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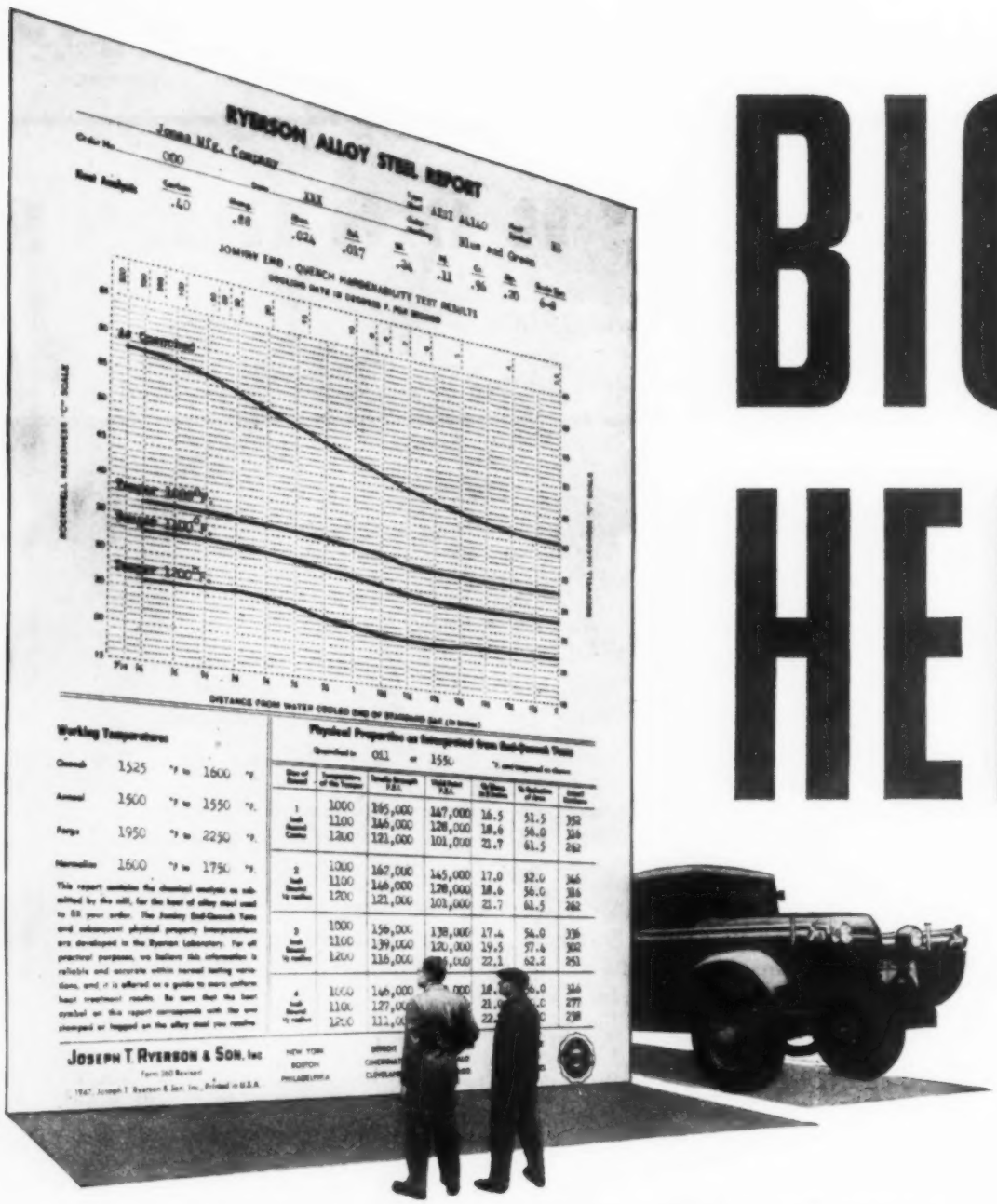

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Principal researches of the Welding Research Council have been metallurgical in nature, and several of them have already benefited related engineering fields — as indeed may be expected of others, still unfinished, on their completion.

Welding Research

SHORTLY after the organization of the American Welding Society in March 1919, the American Bureau of Welding was founded as a cooperative research agency, with representation from the American Welding Society, the major engineering and some scientific societies. Although the principal representation was from the American Welding Society, the Bureau was formally attached to the Engineering Division of the National Research Council.

The urge for this agency was twofold:

1. The necessity to bring to bear upon the problems of welding a broad range of the best scientific and engineering talent that could be made available.

2. The conviction that the cooperative method would not only be more economical from the commercial standpoint, but also enhance the chances of successful solutions and the application of those solutions.

The first 15 years of the American Bureau of Welding were largely occupied in the promulgation of these two basic ideals, although a few notable practical projects were completed. In the early days the codes and standards, since turned over to the American Welding Society, were in the hands of the American Bureau of Welding. Probably the most important, although least spectacular, work of the Bureau was that conducted by its University Research Committee. This consisted largely in stimulating interest in welding problems in the engineering and scientific staffs of the universities, and provided a germinating ground for ideas and the development of men. It is still one of the most important branches of the Welding Research Council.

In 1932 the income of the National Research Council from its endowments was so far reduced that it had to withdraw the financial assistance which had been provided the American Bureau of Welding, so in 1934 this work was reorganized under Engineering Foundation (the research body of the major engineering societies) as its Welding Research Committee and later as the Welding Research Council. By that time many of our interested corporations had awakened to the need for more real research work and were willing to contribute to that end. For the first year of reorganization these contributions, together with a generous contribution from the Engineering Foundation, amounted to about $22,000. The budget has grown steadily to approximately 12 times that modest sum.

At present the two largest research projects are on weldability, largely financed by the American Iron and Steel Institute at about $40,000 per year, and on pressure vessels, more broadly financed, to which the oil industry has so far contributed one third of the sums collected. Its present annual budget is about $60,000.

As a part of the cooperative plan, Welding Research Council has served in some degree as a clearing house for research in welding, not only of this country, but also of the rest of the world.

By Comfort A. Adams and William Spraragen
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Many foreign articles have been translated and distributed to our contributors, and some of the most important of these have been reprinted in the research supplement of American Welding Society's *Welding Journal*. An agreement with the British Welding Research Assoc. for the interchange of literature enables the Council to distribute a considerable number of English publications. Likewise, the Welding Research Council has published some of the most significant reports of the U. S. Government research agencies in this field.

Research Philosophy — In each branch of engineering knowledge we have in varying stages of evolution a rational skeleton of the principles involved. This is sometimes referred to as the "theory" of that field. When a new combination of the phenomena is observed, the inquiring or real research man seeks first the reason why; he tries to explain the phenomena in terms of available theory. If successful, this bit of rationalized information is then hung on the appropriate hook in the skeleton of theory, which gradually grows into a living structure which we know to be sound. This is the process of evolution of all scientific knowledge of which engineering is a part. It is worthy of emphasis — although almost a truism — that even a small advance of this type in any applicational field often yields a greater increase in industrial efficiency than reams of unrationalized data.

We are fully aware of the numerous problems where the need for quantitative information is so urgent that it would be absurd to wait for a more rational solution, which might take years, when a rough, practical, but much more limited solution can be obtained promptly by the empirical approach. Thus, the present Welding Research Council setup includes a group of projects covering the most imminent practical problems, but always with due consideration to the rational point of view, both in plan and interpretation. To this end there is usually attached to each project committee at least one man with broadly grounded scientific mind.

In parallel, there are a few continuing projects aimed at the more fundamental attack on some major problem. An instance would be "the flow and fracture of metals". The most difficult part of a successful attack on such problems is to enlist the best talent with the necessary time and the primary interest. Nevertheless, such researches are making progress and are being supported by some of our largest corporations whose management is convinced that the more fundamental the research, the more productive it is in the long run.

Welding, in its broad scope, includes so many branches of science, and most of its problems are so complex, that the skeleton of theory is still rather sketchy. Moreover, the available test methods often fall far short of covering the need, and we are too apt to accept the results of conventional tests without such careful study as would make possible their sound interpretation.

Nevertheless, in spite of all these difficulties and complexities, the demands of modern industry are such as to constitute a continuing stimulus to rationalize our knowledge as well as the method of attack. Although to the casual observer we are still groping, significant progress has been made. Because of this very urge to rationalize, the work of Welding Research Council has revealed many gaps or weak spots in the component fields. It has not only served as a stimulus to more fundamental, quantitative research in some of these fields, but has sometimes made modest contributions to our knowledge thereof.

The noting of these facts by the Editor of *Metal Progress* was responsible for his request for this article. He has asked the authors to state briefly the important knowledge developed by the accelerated research during the war, and to indicate the most important steps next to be taken.

Since anything approaching a statistical review of the scores of reports would be quite out of the question, only the high spots will be mentioned in the following review of the present status.

Welding Research Progress

Steel — Some 15 years ago the welding industry met the steel industry head-on by announcing that specifications for steel for welding would limit the carbon content to 0.25% and manganese to 1.0%. Starting off with a rather futile interchange of vocabulary, negotiations have continued along much more profitable lines so that we have almost (not quite) reached the millennium where the steelmaker will agree that for many applications greater care and more expensive precautions need be taken to provide steels that are more readily weldable and not so notch-sensitive at low winter temperatures, and the welding fabricator will voluntarily admit that such steels should command a higher price!

Although those percentages of carbon and manganese, in general, still hold good for foolproof steel, a whole series of really basic researches involving cooling-rate measurements (directly and indirectly), with corresponding metallurgical studies, now enables the welding engineer to specify the welding conditions that must be used to avoid undesirable microstructures for a given steel of

given thickness and joint geometry. Some researches now underway point to the possibility that heat treatment of steel before welding — such as quenching and drawing, or spheroidizing — may produce structures which are not so susceptible to the heat effects of welding.

Steels which are susceptible to underbead cracking or cold cracking may require the use of austenitic electrodes or ferritic electrodes specially formulated or coated so as to introduce a minimum of hydrogen into the weld zone. High heat input, preheating, and resulting slow cooling, are helpful in reducing the amount of martensite that would otherwise form at and near the weld.

Although there is still much to be desired in our knowledge of notch strength of steel, some progress has been made. This is one of those problems where the number of variables is rather appalling. In this connection, the work of the Ship Structure Committee and related organizations, such as National Defense Research Council, will have a profound effect on investigations of mild steels, their fabrication and design, for many years to come. Excellent summaries and complete reports are available in the *Welding Journal*. A complete summary of the work would be beyond the scope of this article, but a few of the more important conclusions might be stated as follows:

1. The brittle fractures in welded ships resulted largely from stress-raisers occasioned by poor design or workmanship, combined with the use of notch-sensitive steel at low temperatures.
2. Fractures in large welded and unwelded ship plate specimens containing stress-raisers comparable to those found in ships have occurred at nominal stress values as low as 20,000 psi.
3. Previous ship plate specifications were not sufficiently selective to provide material that reasonably precludes the occurrence of brittle fracture on welded structures within the temperature range in which ships operate.
4. In discontinuities like hatch corners, rounded and flexible details are superior to those showing acute notching and great rigidity.
5. Residual stresses have been determined to be much less responsible for failures than previously assumed.

As far as residual or internal stresses are concerned, the phenomena are exceedingly complex and very difficult to study experimentally. We know that if a weld cools without cracking, plastic flow has taken place within the heated region, but we do not know that the resulting biaxial or triaxial residual stress pockets are harmless. Their effect depends upon the magnitude, nature and direction of the service stresses.

We do know that brittle fracture is encouraged by multi-axial stresses, and that the latter may be definitely dangerous. A very ingenious method, partially nondestructive, has been developed by a Belgian scientist, Prof. Walter Soete, for measuring residual stresses. His method consists of placing electrical strain gages in a rosette, drilling a small hole in the center of the rosette and observing the changes in dimension as registered by the strain gages. In America similar studies have been made of such areas trepanned from plates in suspicious localities.

Of considerable interest is the intensive work by Welding Research Council, of the Ship Structure Committee, and of others abroad, to find a practical small-specimen test which can check the notch strength of steel. At present the only acceptance test widely recognized is the American Society of Mechanical Engineers' Boiler Code Committee requirement that steel shall have a 15-ft-lb. Charpy value at the lowest operating temperature. It is significant to note that plates taken from cracked ships and subjected to the V-notch Charpy impact tests at the temperature at which the ship failed generally indicated that *(a)* plates in which fractures *started* absorbed less energy than those through which the fracture propagated, and *(b)* the plates in which fractures *stopped* absorbed more energy than those in which the fracture started, and those through which the fracture propagated. Some evidence exists that the conventional impact test is not wholly satisfactory for discriminating between steels with different notch brittleness characteristics as determined on tensile specimens 6 ft. wide, internally notched, or on large welded specimens in which restraint is incorporated by means of square corners and plates at right angles — the so-called "hatch corner" tests. Better discrimination is apparently achieved by tests in which the rate of strain is slow, such as a slow notch-bend test or a tear test.

An indication of the reaction of engineers to the research work in this field is the new American Bureau of Shipping's specifications for hull steel, which — through chemistry and physicals — limits the deoxidation practice for plates thicker than ½ in., and permits only fully killed steel above 1 in. thickness.

Along more fundamental lines, the Welding Research Council has sponsored investigations relating the effects of temperature, degree of restraint, and strain rate on brittle fracture. Still lacking are investigations aimed at discovering the real reasons for the difference in behavior of different heats of steel, intended to be identical in quality, as regards their notch sensitivity at low temperatures. In a comprehensive digest of the information that is available on the fracture of steel, sponsored by the Welding Research Council,

John H. Hollomon sounds a word of caution in regard to the use of pearlitic steels in loaded members subjected to shock. (Incidentally, most of our structural and mechanical steels are pearlitic.) He points out that a sharp-ended crack produces a degree of constraint equivalent to raising the transition temperature by about 100° F. That is to say, if a certain sound steel is tough in a V-notch Charpy test at room temperature but breaks in a brittle manner at subzero temperatures — that is, has a "transition temperature" of about 0° F. — its "transition temperature" at the base of a crack is 100° F.; in other words, a specimen of this steel with a crack would fail in a brittle manner if tested at any temperature less than 100° F. According to him this mechanical effect, coupled with the rise in transition temperature in the steel near the joint due to the welding operation, would wipe out any factor of safety provided in the design — as far as operating temperatures were concerned.

It is interesting to note that normal weld metal itself has a considerably lower transition temperature than the best grade of plain carbon steel. A somewhat disconcerting preliminary investigation has indicated that the transition temperature of steel is raised under cyclic loading at stresses even below the endurance limit. Small wonder, then, that Welding Research Council is giving serious consideration to more fundamental studies of flow and fracture of metals.

Of considerable significance is the research work reported by A. B. Kinzel in his recent Campbell Memorial Lecture in which he attempted to tie up weldability and notch sensitivity at low temperature and at the same time to provide an acceptance test. This investigation is outlined in the November 1947 issue of *Metal Progress*. As he pointed out, the notched slow-bend specimen appears to be a satisfying analogue to service performance when lateral contraction parallel to and below the base of the notch is used as a measurement of ductility. The test is performed at the lowest temperature anticipated in service. The notched slow-bend specimen with longitudinal weld bead permits the investigator to vary welding conditions and techniques; it comprises plate thickness, and contains all heat-affected zones in the notched condition. It is possible to prepare and test a "platform" specimen directly from a steel heat in less than 4 hr. from teeming.

For a criterion of service performance, Dr. Kinzel suggests that the specimen in question be used with a lateral contraction of 1% as a minimum limit, and that the test temperature for indoor and marine service be set at −20° C. (−4° F.), for outdoor service at −40° C. (−40° F.), and for low-temperature service in the chemical industries at 10° C. (18° F.) lower than the anticipated minimum service temperature.

He further states that carbon is the most important single element in determining the embrittling temperature. Alloys, however, generally have a major effect in improving the behavior of the steel — that is, in lowering the embrittling temperature for a given strength level. Further work may well enable the metallurgist to make a quantitative estimate of the effects of individual alloys or combinations, but such work must await the determination of at least one very important factor in steelmaking not as yet established. For example, Kinzel and his co-workers were unable to ascribe the cause of lower embrittling temperature to the ordinary chemistry (including gases such as nitrogen and hydrogen). However, other work indicates that nitrogen may be a factor in this phenomenon.

Another very important investigation at the Illinois Institute of Technology, sponsored by the Welding Research Council, has been on the stress-corrosion cracking of mild steel. It had occurred to the present authors that the phenomena of stress-corrosion and notch-sensitivity of steels at low temperatures might be closely related — perhaps due to the same cause. We recalled that welds made with the old bare-wire electrodes were notoriously low in notched impact resistance (Izod and Charpy) even at room temperature, and had practically negligible resistance at low winter temperatures. The cause was attributed by the late S. W. Miller to nitrides. The impact resistance of such welds was not improved by annealing. Therefore, when McDonald and Waber came out with their theory that stress-corrosion, caustic embrittlement and strain-aging are closely related it seemed logical to theorize that nitrogen, which was believed by these investigators to be the cause of the above phenomena, could be closely associated with the notch-sensitivity of steels at low temperatures. A practical finding has been that aluminum additions to fully killed steels protect them from caustic embrittlement, stress-corrosion, and aging, and improve their notch-sensitivity. Further investigation is needed to discover the part played by nitrogen.

Alloy Steels — On the basis of equal tensile properties of the base steel and the welded joint, it was found that copper alloy steels (1% Cu) generally have considerably better notched-bar toughness in all zones of the weld than plain carbon steels (0.30% C). The maximum hardness found in the heat-affected zone is lower in copper steels than in the corresponding copper-free steels of equivalent strength.

Results of crack susceptibility tests and tensile tests of butt welds indicate that a carbon-molybdenum steel (0.20% max. C), quenched and tempered, can be successfully welded in ½-in. plate with E10010-type electrodes without preheat, and that yield strengths of 90,000 psi. and tensile strengths of over 100,000 psi. can be obtained in the welded joints after a full stress relief.

It has also been found that corrosion cracking of austenitic stainless steels requires a rather critical combination of heat treatment, applied stress and corroding environment.

Electrodes — Typical electrodes in the E6010, E6012, E6013 and E6020 classes produced arc atmospheres containing 35 to 40% hydrogen and caused severe underbead cracking in crack-sensitive steels. For such steels, the use of low-hydrogen, lime-coated ferritic electrodes is advocated.

Graphitization — Various remedies have been proposed to retard graphite nucleation in welded carbon-molybdenum piping for high-pressure, high-temperature service. Only a few of the more recent proposals will be mentioned in this review. Some of these have not yet been fully explored:

1. It is proposed that iron-base alloys containing not more than 0.06% carbon and alloyed to provide adequate creep strength be given further consideration as materials for high-temperature steam piping.
2. The greater the carbon content the greater is the rate of graphitization. Both molybdenum and chromium appear to inhibit graphitization. This latter element is widely considered to be the best means of avoiding graphitization; the necessary amount seems to be at least 0.5%, and possibly more.
3. Lengthy stress relieving treatment at 1370 or 1400° F. is a better safeguard against graphitization than conventional stress relieving at 1200° F.
4. Low-aluminum deoxidized steel (0.5 lb. Al per ton or less) or straight silicon deoxidized steels appear resistant to present steam temperatures.

Design

A large amount of research of the engineering variety has been carried out by the Welding Research Council to secure unit design data for bridge engineers about the various forms of butt and fillet joints, plug and slot welds, and of welded elements in a structure. Fillet welds and riveted joints both provide undesirable stress-raisers. Sooner or later, work of a more fundamental variety will have to be undertaken on this problem.

In old railroad bridges of pin-connected design it becomes necessary to shorten one or more eyebars in a group to equalize the stresses carried by each. A method has been developed whereby the eyebars are heated with oxy-acetylene flames and then upset by turnbuckle clamps. This takes less time and is more economical than any other method. The results of tests conducted by Welding Research Council indicate that flame shortening does not materially affect the fatigue strength of the bars, whereas comparable tests on representative eyebar specimens shortened by other more costly methods showed that the fatigue strength was reduced to from 35 to 50% of the original eyebar. It is estimated that if this method were used by the railroads in tightening all the loose eyebars, the resulting saving would be about $1,000,000 per year.

Extensive investigations of full-size welded connections for building construction and various details used for them have been in progress for about 12 years at Lehigh University under the auspices of the Structural Steel Research Committee of the Welding Research Council. Recently published reports, together with some 14 previous ones published since February 1934, provide a comprehensive appraisal of the comparative merits and the behavior under static load of various types of beam-end connections. Since all of the types tested have been used successfully by constructors for a number of years, there is a background of supplementary experience available.

Through the research at Lehigh, and the studies based upon it, a more efficient and more rational method of design has been developed for welded building connections than existed heretofore for riveted steel frames. At the same time, through the provision of standardized details and design diagrams, the designer has been relieved of much of the routine calculations. Furthermore, there has been provided for him a sound basis for the design of connections for rigid and semi-rigid framing.

The whole field of design offers immense opportunity for original thought and research. Mention has already been made of the effect of change in design in ships' hatch corners. The hatch corners used on later "Liberty" ships (U. S. Coast Guard Code 1 modification) were found to be over 50% stronger than the ones designed on the basis of maximum nominal stress, and were found able to absorb more than 16 times as much energy before major failure.

Two of the new designs were unique in that they were the only ones which did not fail at the corner of the hatch and behaved in a ductile manner. One of these, involving the use of a hot-formed corner plate having radii in both the horizontal and vertical planes, gave an increase in maximum stress before fracture of 124% and an increase in energy absorption of over 2800% as compared with original Liberty ship design.

An investigation of some magnitude was

undertaken to ascertain the effect of high residual stresses on the resistance to high rates of strain of butt welds in heavy H-section beams. The byproduct of scientific data and mathematical analysis of the behavior of beams under impact loading will be considered a monumental piece of work for years to come.

While considerable data were thus accumulated under normal room temperature conditions, which indicate that the behavior of the plain and welded beams was not radically different, the question was raised as to the possible effect of low temperature — particularly in view of the phenomena of embrittlement at low temperatures accompanied by local conditions of restraint. A limited number of pilot tests at −40 and −62° F. furnished additional factual information which suggests further studies.

Resistance Welding

Because of the large amount and variety of research in the resistance welding field during recent years (notably at Rensselaer Polytechnic Institute), only general mention can be made of a few outstanding examples.

A brilliant piece of research — taking into account a metallurgical principle that the toughest steel structures are produced when martensitic structures are tempered — led to the production of tough spot welds in hardenable steels. A controlled circuit in the spot welding equipment allows proper time for welding, then time for quenching to martensite, followed by a timed current for tempering — all taking no longer than required to make an ordinary spot weld. Increased strength and toughness, sometimes tenfold, result from the use of this method.

We have learned how to treat the surface of aluminum alloys chemically to reduce the high contact resistance of surfaces of mill stock and thus permit the making of consistently good spot welds. The development of a double-pressure, condenser-discharge welding machine, after research, eliminated internal cracking in spot welds in aluminum alloys. In such welds the forging pressure must be applied neither too early nor too late, and after the peak current has been reached.*

The Welding Research Council has two researches now underway by which it is hoped that the fatigue endurance limit of spot welds in alternate tension and compression can be raised from 10 to 20% of the shear value — that is, doubled.

Optimum conditions for the spot welding of magnesium alloys have also been determined.

The fundamental conditions for good projection welding have been determined so that suitable procedure specifications may be issued. Results from recent investigations permit the projection welding of steel plate up to ½ in. thick. One trick is to use a preliminary current for preheating and providing suitable contact area before using the heavy welding current.

The mystery of the so-called advantages of pulsation welding has been removed.

A dome-shaped electrode is now recognized as best for practically all spot welding.

In the newer machines for resistance welding, storage battery and polyphase alternating current equipment will extend the applications of resistance welding to heavier gages of aluminum and of steel plates.

Precise temperature measurements and power studies are showing some excellent mathematical relations between the many variables in the flash welding of structural aluminum alloys. The mathematical relations are so general and fundamental that they can be applied directly to the flash welding of metals other than aluminum.

Conclusion

One cannot work long in the field of welding research without realizing that neither pure nor applied science can be divided up into independent or isolated compartments. The solution of most of our problems is quite impossible without substantial knowledge of fundamental principles — not only of metallurgy, but also of several branches of physics and chemistry. We are drawn inevitably into practically all fields of engineering, and the results are of practical value in all branches of the metals industry, including all manufacturers and fabricators of metals.

Although Welding Research Council was originally fostered chiefly by the American Welding Society, it is now sponsored by practically all of the older engineering societies, since its work cuts across all of their fields. In fact, it is sometimes necessary to initiate projects which at first sight would not appear to belong to the field of welding research, but are necessitated by lack of knowledge in those underlying fields.

It is thus our hope to gain even wider support and cooperation from all interested groups. The need is great and obvious to all who have struggled to make welding safe as well as economical in its numerous and increasing fields of application.

*These and other aspects of recent work on spot welding of aluminum are being covered more fully in a comprehensive review by Gerard H. Boss now running serially in *Metal Progress*.

An attempt to present some fundamentals of the heating process and a discussion, based thereon, of a few difficult problems in the design of heating furnaces and the heat treatment of steel. (Adapted from remarks made before an American Gas Assoc. conference in April.)

Furnace Design for Better Utilization of Fuel

REQUIREMENTS for heat application in the processing of metals are quite varied; at times it seems that every part presents a different heating problem! One may well investigate, then, the viewpoint from which may be analyzed the factors influencing furnace design and fuel utilization.

The presentation may be simplified by limiting the discussion to ferrous alloys. In connection with the heating of steel, two primary divisions of the inquiry may be recognized: *(a)* heating rates or problems in heat application, and *(b)* surface effects, or problems other than the transmission of heat energy.

To date, much of the progress made in industrial heating practice has been due to developments in refractories, heat resisting alloys and temperature controls. These we may not neglect; yet it seems advisable, from the process standpoint, to develop a very general presentation of heating principles. From such a development it is hoped that processing problems may be analyzed in a somewhat quantitative manner. Some of the needs and problems may then be illustrated by discussing a few special processes.

Heating Problems

As a basis for discussion, a theoretical curve for differential heating will be employed. This general plot (Fig. 1) will assume that the heating rate is directly proportional to the temperature differential — by "temperature differential" meaning the difference in temperature between the source or head temperature and the temperature of the piece's surface. This idealized curve has the advantage of being readily analyzed. All of its properties are known, and the plot may be easily constructed.

This theoretical curve is based on the following assumptions:

1. The limiting factor is the transfer of heat to the surface, and not the conduction of heat to the interior.
2. The coefficient of heat transfer does not vary with temperature.
3. The specific heat of the material being heated is constant, and is independent of temperature; furthermore, no phase changes occur in the temperature range employed.

A few remarks concerning the validity of these simplifying assumptions are in order.

For the majority of the problems found in the heating of steel parts, the transfer of heat to the steel surface *is* the controlling factor. However, the coefficient of transfer varies greatly with temperature when the transfer of heat is by radiation. Also, the specific heat of steel is by no means constant as the temperature varies. Nevertheless, these variations from the theoretical may be

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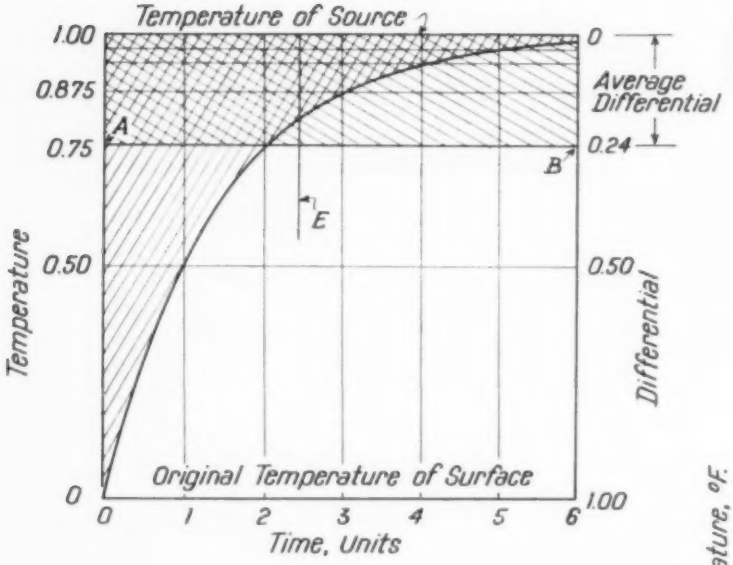
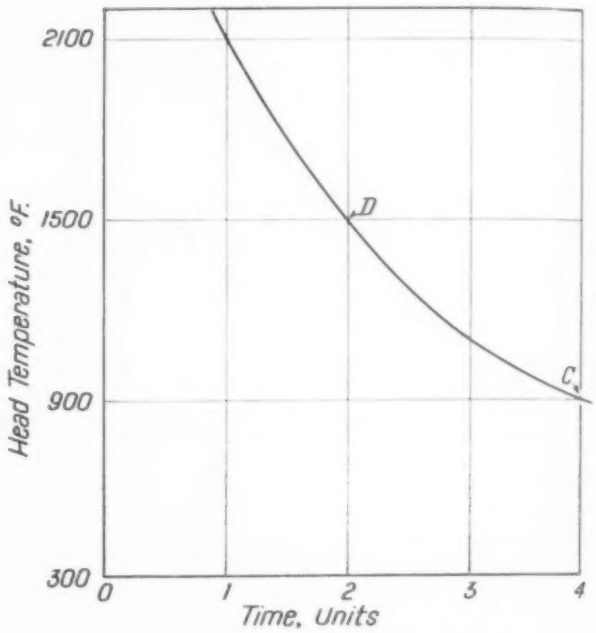


Fig. 1 — Theoretical Curve for Differential Heating, Assuming Constant Coefficient of Transfer, Constant Specific Heat, and Absence of Phase Changes

Fig. 2 (below) — Transfer of Heat by Radiation to Steel Pieces of Uniform Section (Time to Reach Given Head Temperature) Is Much Quicker as Head Temperature Increases



analyzed in conjunction with the curve, and it may be used for demonstrating heating rates, zoning, couple location, and the principles of heat application.

The graph shown in Fig. 1 is actually the common half-life curve. The abscissa scale, x, is divided into six equal time divisions by the vertical ordinates. The curve is constructed so that the differential at the end of each time period is one half that found at the beginning of the time period. The crosshatched area between the Y axis and the line Y = I (the temperature of the source, or line of zero differential) above the curve represents the total heat to be added at the beginning of the heating operation. Similarly, the area to the right of any vertical ordinate or time division represents the heat to be added to complete the heating operation. Also a line, AB, drawn horizontally through 0.24 on the differential scale (at right) is related to the average heating rate for the complete time cycle, in that the area above this line equals the total area above the curve representing total heat input.

What interpretation may be made from the curve of Fig. 1 concerning an application of furnace heating where the transfer is chiefly by radiation? We may begin by determining the minimum time to reach given head temperatures, with standard test pieces, originally at room temperature. The test conditions are carefully chosen; the furnace is evenly heated to the head temperature before the test piece is inserted; the test piece is so small compared to the furnace capacity that the thermal equilibrium of the furnace is not disturbed; adequate pyrometers register the temperature of the sample. This is a condition of low heat input to the charge, and we find experimentally that the curve of Fig. 1 is obtained for all practical purposes for a wide range of head temperatures.

However, since the transfer rate for radiation increases rapidly with temperature, the *time* period decreases as the head temperature increases, even though the higher the head temperature the greater the amount of heat required to bring the test sample to the furnace temperature.

For example, assume that the first experiment in a series is made with the furnace at 900° F., and that the time required for the sample to be heated from room temperature to 900° F. is 4 time units (Point C, Fig. 2). On the second experiment with the furnace at 1500° F., it is found that only one half the former time period is required — that is, 2 time units (Point D, Fig. 2). Again at 2100° F., the time period to temperature is but one half that necessary for 1500° F. Relative times to heat from 70° F. to various head temperatures are therefore shown in graphical form in Fig. 2.

Now let us extend this general analysis to a consideration of the uniformly loaded furnace hearth, considering such things as furnace capacity, heat application, and control of the tempera-

ture of the charge. (An analogy may be made between the batch and the continuous furnace, by comparing time periods of the batch type with zones in the continuous unit.) The entire analysis depends upon the heat transfer possible in a uniformly loaded, evenly heated furnace when the wall temperatures of the furnace exceed at no point the desired temperature.

It is found that the curve of Fig. 2 may be used in such an analysis and that the heating capacity per unit of hearth is inversely proportional to the time periods as plotted in that figure. Maximum heating capacity requires a choice of at least two zones for the continuous unit and two

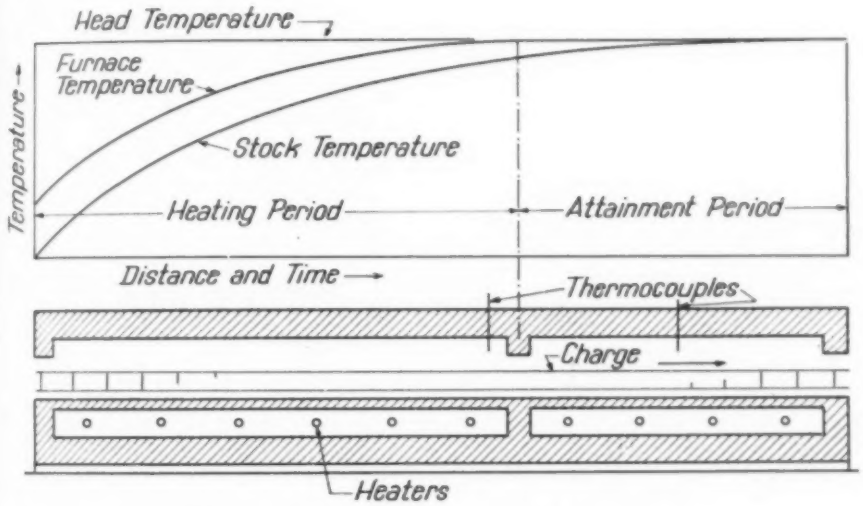


Fig. 3 — Sketch of Continuous Furnace, and Approximate Temperature Relationships Between Furnace and Charge

time periods for the batch furnace. The zones (or time periods) are periods of constant heat application. The heating period, following the entrance or charge of cold steel, is a period of high heat input as at the left of Fig. 2; the temperature-attainment period is one of low heat input at a practical rate approximately 20% of the rate of heat input for the heating period.

With reference to the heating curve of Fig. 3 for a continuous furnace, the heating period is one where the wall temperatures are continually increasing in temperature from door to division wall; the temperature-attainment period is one where the walls are at the chosen head temperature. If we divide the heat inputs during the heating period and during the temperature-attainment periods in the 5 to 1 ratio mentioned above, 83% of the heat will be absorbed during the first and 17% during the second stage. Turning to Fig. 1 we find that the area above the curve is divided in this 83:17 ratio at vertical ordinate E; to fulfill these conditions the two time periods (or zones) should be approximately equal. Practical considerations of heat applications will generally call for a slightly different proportion, for example, 60% for the heating period. (Such practical considerations include such things as the fact that a longer heating period decreases the heat release per unit area of the hearth; on the other hand, too high a heat release may cause refractory troubles in underfired furnaces.) For the continuous furnace sketched in Fig. 3, the zoning and approximate heating curves are given for a 60-40 division.

This sketch also shows the thermocouple location for the two zones. The couple for the heating zone is located at the end of the zone in the direction of stock movement, as this is the point of highest wall temperature. The couple for the final zone is located in the center of length, since this zone should be of uniform temperature for its entire length. Both couples are controlled at the desired head temperature.

It remains to define the term "hearth area", and to give the capacity loading under which controlled heating may be maintained. Hearth area will be taken as the width of the hearth which is uniformly

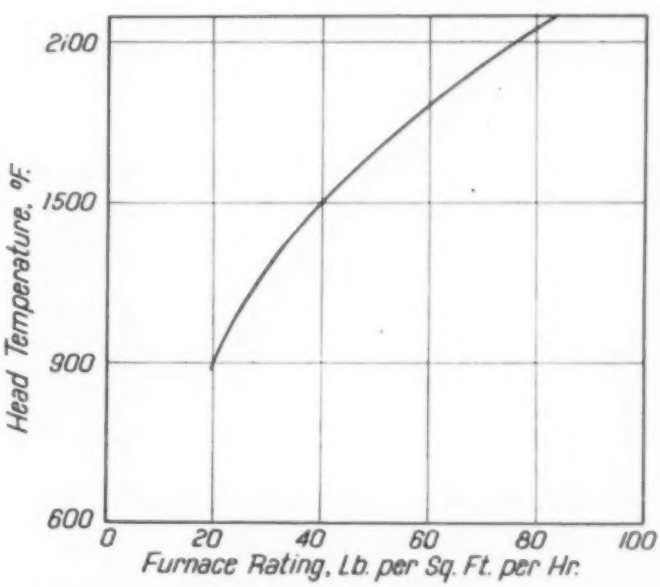


Fig. 4 — Relationship Between Continuous Furnace Ratings per Sq.Ft. of Hearth and Head Temperatures

covered by the charge multiplied by the total length. Spacing is allowed along the furnace length, but the hearth should be half covered, at least, to obtain this capacity. The rating in pounds per square foot of hearth area per hour ranges from 20 at 900° F. to 80 at 2150° F. The relationship with temperature is shown in Fig. 4.

For a great many heating applications, reasonable care in heat application and proper zoning and loading will assure a uniform product, with no possible chance of overheating thin sections — even though temperatures are measured at very few points. It is easily recognized that recirculation fans will increase the transfer rate and thus increase the productivity of the furnace, particularly at the lower temperatures. Thus, the real problems are found when process requirements make faster heating rates advisable or where special atmospheres must be maintained.

It is obvious that if the heat source is from a temperature much higher than the desired one, a much faster heating rate than that shown in Fig. 4 is possible. The use of a differential temperature — that is, a different (usually higher) temperature in the heating period than in the attainment period — generally calls for a special treatment, both for control and for heat application. This may be illustrated by an operation where only a small amount of heat is required in quite a remote location.

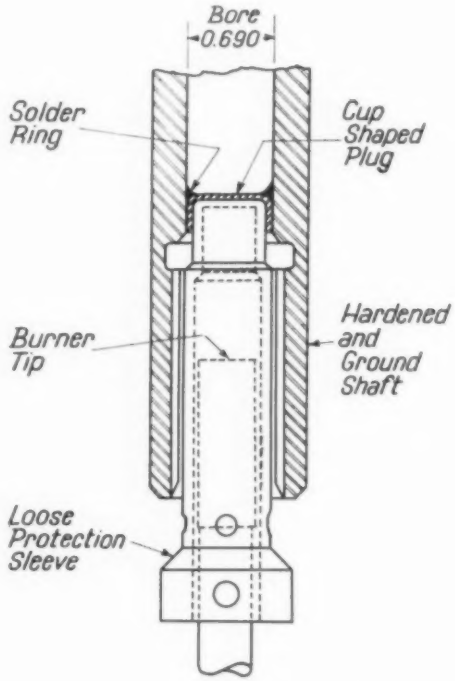


Fig. 5 — Scheme for Soldering Internal Plug Within Bore of Hardened and Ground Shaft

Example of Differential Heating

The problem is to solder a plug in a bored shaft, this cup-shaped plug being midway of the bore (which is slightly over ⅝ in. diameter). The shaft initially is hardened and ground, and the outside surface may not be heated over 300° F. A protection sleeve of heat resisting alloy is fitted loosely in the bore of the shaft, and the plug fits over the closed end of the protection sleeve (Fig. 5). A ring of solder wire is placed on top the plug. Heat is to be transferred to the plug from the hot sleeve-end at a rate which will melt the solder ring in a short time.

A very small pilot burner is employed for heating. It is rated at 1 cu.ft. of natural gas per hr. This miniature burner is built in two parts with threaded connections, the body being of steel and the tip of alloy. It has the customary auxiliary ports around the orifice for flame retention. The tip, however, is lengthened so that heat may be supplied to the incoming gases, and in open air it will be maintained at about 1000° F. In this manner a very stable, short flame may be established. After lighting, the protective sleeve is placed directly over the burner tip, and the gases of combustion blow back in the annular space between outside of tip and inside of protection sleeve and leave without coming in contact with the hardened shaft. The top part of the sleeve, over which the shaft assembly is to be placed, is thus held at approximately 1500° F.

The complete operation of soldering the plug takes 1 min.; it is accurately timed by removing the shaft from the tip assembly. At that time the outside of the hardened shaft is barely 200° F. The success of such an operation depends entirely on close control of the gas-air mixture furnished the small burner. Such extremely small amounts of gas and air would be hard to maintain in the correct ratio, except that a 6 cu.ft. per hr. tip is connected to the manifold to which it is attached by a hose connection. It serves to light the small tip on starting and this auxiliary burner is carefully given the proper mixture for a sharp flame. Once this is established, the mixture for the small tip, on the same manifold, must be the correct one, and the auxiliary flame applied to the tip makes lighting a simple operation.

While this operation may seem far removed from furnace work, either in continuous or batch types, many applications of differential heating are found in the high-temperature field, particularly in hot forming and forging. At elevated temperatures, oxidation occurs rapidly and makes a fast heating rate desirable; holding for any time increases the scale. Here, as in the soldering illustration given, each problem has its own peculiarities and care must be given to the processing.

It must be remembered that heat transfer, other things being equal, is directly proportional to the area exposed for the part being heated. When high differentials are employed, irregular sections of the stock may cause uneven heating, although the heat source may be from a uniform (and high) temperature. Thus, the ends of rounds or squares and the edges of plates have much greater areas to which heat is transferred than do the interior sections.

A glance at Fig. 4 will clearly show what may be done to decrease the time of heating operations. Since many forging practices depend on high differential temperatures, much remains to be done to make them safe and controllable. Extreme care in heat application, timing and temperature control is necessary for maintaining acceptable quality on many other operations. This field offers an excellent opportunity for improved methods in gas utilization, but much careful study is required to make such applications entirely successful from both economic and quality considerations.

Atmosphere Applications

A great number of heating operations are concerned with protective atmospheres. While a number of processes are accomplished in the shop by controlling the products of combustion in direct-fired furnaces, precise control of surface effects generally demands an atmosphere supply entirely separated from that generated by the heating source. While both heating and atmosphere problems deal with the control of chemical reactions, the demands of a protective atmosphere are much more exacting from the gas-supply standpoint than are those of mere combustion.

Since we are discussing the problems of the processor in the metal industry, it might be well at this point to emphasize the importance of a consistent gas supply as furnished by the utility. When the customer is interested in heating only, then a gas supply reasonably constant in B.t.u. value will generally satisfy the operator, even though the chemical composition of the gas may vary from day to day. The reason for this, of course, is found in the circumstance that properties of commercial fuel gases are such that the gas-air ratio for combustion is almost constant for a given B.t.u. value. While the combustion characteristics may vary somewhat with composition, it is generally a simple matter to provide combustion facilities that will operate correctly as long as the available heat in 1 cu.ft. of the fuel gas does not vary greatly.

On the other hand, when that same gas is used for preparing atmospheres, changes in compositions may often cause operating difficulties.

Without attempting to oversimplify the problems of atmosphere applications, their solution may be found in the control of gas composition and flow. Atmospheres for ferrous alloys commonly consist of a "carrier gas" to which additions are made as desired. The characteristics of a carrier gas which would most nearly satisfy all varieties of atmosphere operations may be listed: Such a gas should be relatively inert to steel surfaces — that is, slow to react with carbon and iron. It should be easily made in large quantities, and relatively inexpensive. The ideal carrier gas should be nonexplosive when mixed with air at low temperatures. It should be of such nature that its capacity for decarburization can be readily checked or verified.

The composition of such an ideal gas should contain at least 20% carbon monoxide (CO); it would be satisfactory up to 30% CO. The balance would be nitrogen. The carbon dioxide content (CO_2) must be held to a trace; hydrogen must also be eliminated because of its explosiveness. No hydrocarbons are allowable.

From such a specification, a refined producer gas whose CO_2 might be removed would seem to be the answer. While such a carrier gas is now used in industry, no large-scale production is feasible; present generators for gas of this composition are generally quite small. When the desirability of this composition is appreciated, further development in means for its preparation would greatly reduce the problems of atmosphere applications — at least for steel treaters.

For a processing illustration, the manufacture of a clutch spring formed from a flat plate will be discussed. The blank is of approximately $\frac{1}{16}$ in. section, 8 in. in diameter with a 4-in. diameter hole in the center. This blank is formed cold, deeply corrugated, like the ruff or ornamental collar worn in court a few centuries ago. The steel must contain enough carbon to harden to Rockwell C-55 in a die quench with oil as a coolant.

Such a blank made of S.A.E. 1065 presents a variety of problems. Due to the high carbon, and to the care which must be taken in rolling (the thin plate must be cross rolled to meet required spring properties), close thickness tolerances cannot be held. Both surfaces of the plate must therefore be ground down to nondecarburized metal. Since the forming operation on the finished blank is a very severe one, a spheroidizing heat treatment is required, yet even with this softening of the metal, cracks may be epidemic.

The present process uses a commercial low-alloy plate, low in carbon (0.13% C). It is rolled

to size, eliminating the grinding operation. The mill finish is excellent. Blanks are cold formed without the spheroidizing operation. Carbon is then added to the formed spring, so that the entire section is of a homogeneous carbon content; to obtain desired physical properties for this steel, the carbon must be brought up to between 0.40 and 0.50%. It is this addition of carbon during final heat treatment with which we are now concerned.

Recarburizing Cold Formed Springs

A vertical pit-type furnace with a retort 36 in. in diameter and 48 in. deep is employed. A charge consists of 9 strings of 38 springs each, or 342 pieces. The rods carrying the springs are suspended from a spider, and each spring is separated from its neighbor by a small spacer. Each spring weighs approximately 1 lb. and since the carbon content is to be raised from 0.13 to 0.45%, slightly over 1 lb. of carbon must be added to the steel in the entire charge.

Immediately upon loading the heated retort, the carrier gas is supplied and with it a suitable flow of natural gas. This is done to purge the retort completely before the charge is heated to a temperature at which oxidation with trapped air may occur. The function of the natural gas, supplied during the heating period, is also one of providing an atmosphere of sufficient carburizing capacity *before* the rate of carbon demand by the steel becomes excessive. (For such a light load, the rate at which carbon is absorbed by the steel becomes quite high as 1600° F. is reached, due to the large surface area exposed to the gaseous medium.) The heat input is cut to half the initial rate as the thermocouple reaches 1525° F., in order to insure temperature uniformity for all parts.

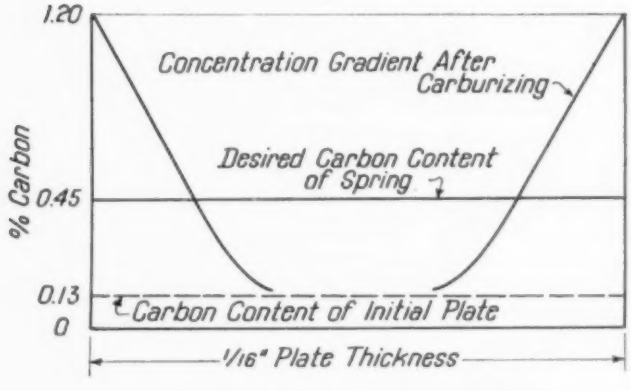


Fig. 6 — Carbon-Depth Gradient Through Plate Spring at Various Stages of Processing

The charge is held at 1625° F. for 1 hr., which constitutes the effective time for adding carbon. The temperature is then raised to 1700° F. and the natural gas supply is discontinued. After holding for 3 hr. at 1700, the load is allowed to drop to 1650° F. by cutting off the heat supply. The function of this period is to permit the carbon concentration gradient to level out, and here the carrier gas composition is an important consideration. By maintaining a slight pressure in the retort, contamination with air is eliminated. During the diffusion cycle, the atmosphere must be practically neutral to carbon — that is, no carbon is to be added or taken from the steel surfaces. A diagram, Fig. 6, will illustrate the process in terms of carbon flow and stock thickness. The principles whereby the carbon-depth gradient can be calculated and the carburizing and diffusion periods estimated have already been expounded by the present writer in *Metal Progress.*★

This illustration is given to bring out the importance of carefully controlled periods, both of gas supply and of heat application. Many other commercial applications of far less intricacy find gas an indispensable fuel in controlled processing. For example, in the very common operation of carburizing automobile engine camshafts, the shafts are hung endwise from the cover of a pit furnace. In such a closely packed charge the fixture-load ratio is extremely small, and the handling problem is quite simplified.

Conclusion

The extreme variations in metallurgical requirements and production demands in the heat processing of metals necessarily make a presentation covering the needs for improvement quite general in character. Certainly an approach based on process fundamentals is helpful in determining what these problems really are. A complete description of controlling factors would be quite lengthy and involved. If this paper is somewhat helpful in illustrating the method of attacking these problems, its purpose is fulfilled.

★"Case Depth" — an Attempt at a Practical Definition, August 1943, p. 265.

Controlled Gas Carburizing and Diffusion Cycles, March 1944, p. 484.

Maximum Carbon in Carburized Cases, April 1944, p. 683.

An Analysis of a Typical Carburizing Gradient, June 1944, p. 1111.

A Formulation of the Carburizing Process (Wilson T. Groves, co-author), Sept. 1944, p. 488.

Reactions Between Hot Steel and Furnace Atmospheres, Jan. 1945, p. 84.

Atmosphere Applications — Equipment, Methods and Process Cycles, April 1945, p. 713.

In the principal portion of an address before Engineers' Council of Houston (Tex.), Commissioner Pike outlined the metallurgical work necessary to provide creep-resistant alloys, inert to radioactivity, for tubes at 2000° F. in "boilers" fired by atomic energy, and suitable fluids (possibly molten metal) for transferring heat from reactor to engine.

Metallurgical and Economic Problems of Atomic Power Plants

As you know, the whole atomic energy program with all its expected outlets is based on uranium, and that part of uranium which is known as uranium 235 represents only a hundred and fortieth of the element as found in nature. Uranium 235 is a natural isotope of uranium; U^{235}, then, is the sole fissionable material occurring in any quantity in nature and is the basis of atomic energy as we know it. Sometimes U^{235} is used directly after having been separated from the other kinds of uranium, U^{234} and U^{238}, in the nation's enormous atomic energy plants at Oak Ridge, Tenn.; sometimes it is used to manufacture out of the abundant isotope U^{238} a new man-made element, plutonium 239, as in the nation's massive nuclear reactors at Hanford, Wash.; and it can be used, although this is still largely a scientific curiosity, to manufacture from thorium an isotope of uranium not found in nature, U^{233}. All of these, namely, U^{233}, U^{235} and Pu^{239}, however obtained, are fissionable materials and can be used for either warlike or peaceful projects. Whether we like it or not, we find it impossible to completely separate the idea of atomic energy from the weapon. It would be wonderful if we could, but apparently it is just one of those facts of nature with which it is useless to argue.

The economic aspects of atomic energy so far as we can now predict seem to lie in two distinct fields: one is power, the other involves the use of the so-called radioactive isotopes. There is, however, a third group of decidedly interesting economic prospects which come as byproducts of work necessitated by the peculiar requirements which met the pioneers in the nuclear art. This is information that has been gained, and will be gained and further elaborated, in various fields of science, engineering and technology in order to handle the unique problems as they arise in the other two fields.

First as to the generation of power:

The problem of net, usable power from nuclear reactors seems to divide itself pretty neatly into two questions: First, can such power be obtained at all? And, second (if the answer to the first question is "yes"), how soon and how far can it be expected to enter into competition with other sources of power?

The first question can, I believe, be answered affirmatively with the qualification that there is a considerable time element involved. A working plant producing more power than the auxiliaries consume can hardly be expected in less than five years, and might be as long as 10 or 15. We expect to get some power out of a reactor now under construction at Brookhaven, Long Island, somewhere around the end of 1949. However, this reactor is not being built primarily for power production and our best guess at present is that it may produce about enough to operate half the

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auxiliary equipment such as pumps and blowers which are a necessary part of the reactor setup.

Up to date, no one acquainted with the problem has any reasonable hope of getting power from a nuclear reactor in any other way than by first converting the energy released by the fission of the elements U^{233}, U^{235} or Pu^{239}, whichever is provided, into heat, as in the present usage of conventional fuels. This is to be regretted, because heat is the lowest form of energy, and to go on from heat to something that turns round and round and gives us, let's say, electricity, means the loss of around three-fourths of the energy originally released. It also seems obvious, to most of those who have given study to the matter, that for highest efficiency the heat will have to be on a considerably higher level than the ones we are accustomed to in conventional power production. 1800 to 2700° F. seems to be about the range to shoot for.*

The source of atomic power, the chain reacting pile, is, you see, merely another boiler room, leaving the rest of the power plant the same thing as it is now. As in the conventional boiler, we have to take the heat out in the form of steam and put it into a turbine, so in this case we will have to take out the heat in the form of something very hot, probably not steam, possibly some inert gas, or possibly a liquid metal, and probably will have to do another set of heat exchanging outside of the pile, so that we can get something that will run either a conventional steam turbine or some form of gas turbine. For a variety of reasons, some of them to be mentioned a little later, it will probably be impossible to make high pressure steam in a chain reacting pile and use that steam directly as we now do in the ordinary power plant.

Even if we were merely dealing with the ordinary power plant, the question would immediately arise as to whether the ordinary or alloy steels used in boilers and heat interchangers can stand up as a good structural material at these heat ranges. The answer would be in some doubt, but I think it turns to an unqualified "no" when you consider a third requirement which is not present in ordinary heat engines.

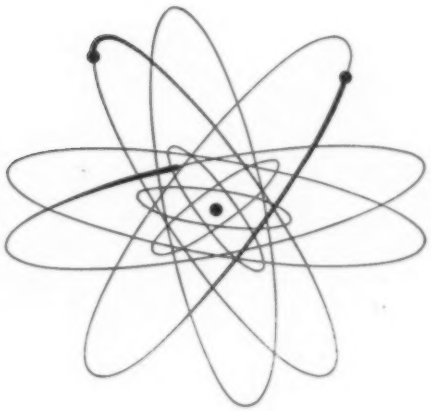
The nuclear reaction (or "fission", so-called) is carried forward from one uranium atom to the next by means of a fundamental particle freed from the first atom. It is called the neutron. If something intervenes to absorb the wandering neutrons the chain is broken and the reaction stops. One of the essentials of a nuclear reactor, then, is that too many neutrons be not wasted either to the outside of the machine or through absorption in the reactor itself. Steel, the iron alloy, does not look suitable for this purpose.

So we have on our hands a metallurgical problem. Success in building power reactors seems to call for a metal of good structural strength (equivalent to or better than steel) which will stand considerably higher temperatures than conventional steel, which in addition will not absorb too many neutrons and thus slow down or stop the reaction. Furthermore, if possible, the structural material should be one which could eventually be produced at a reasonably low cost. Finally, its design and material must be *reliable*. Within the pile is radioactivity of an intensity and quantity hitherto undreamed of on this earth, which will make it impossible to do repair and maintenance work except by remote control directed by men behind very heavy shielding.

I am not certain just what direction the thinking is taking as to specific metals that can be used, and if I were certain, I probably could not discuss it. But a glance at the periodic table of elements, and some rough knowledge of the plentifulness of the elements in nature, shows — to pick one — titanium as a possible candidate. Titanium apparently has a strength-weight ratio better than good structural steel. It seems to stand up under high temperatures very well indeed, and let us say for the sake of argument, although I don't know whether it is true or not, that it has a very low neutron absorption coefficient. In addition, titanium is a very plentiful element. It happens not to have been used much in industry except as an oxide as a base for paint. While it is useful as a minor element in special alloys, as a pure metal it hardly exists at all. It is in about the same state that aluminum was 80 or 90 years ago. If titanium turns out to have the qualities that we want, there is no immediately obvious reason why it can't be produced in large quantities and at quite low cost per pound.

In other words, this problem of the structural skeleton of the reactor looks like a difficult, time-consuming job, but one that is soluble on lines that are familiar to metallurgists and engineers. This leads me to mention, in passing, the third group of economic considerations mentioned at the outset

*Editor's Comment — The temperatures quoted are within the smelting range (far higher can of course be generated). An entrancing future possibility (?) is a shaft furnace whose refractory walls are chambered for the fissionable materials, insulated against loss of heat and radioactivity outward, but passing heat continuously and all but inexhaustibly to the descending column of ore, flux and reducing material within. Disposal of radioactive slag and furnace gases, and the later separation of stable from unstable metals issuing from the tap hole, are additional problems that future inventors can tackle in commercializing the above suggestion.



—byproducts of necessary work in the other two groups. Many of these will apply to metallurgy. The complete metallurgy will have to be worked out for several metals which have previously been neglected. Again, various coolants or heat exchangers will be studied, liquid or gaseous elements, compounds, metals even, which may end up as extremely useful in industries having no relation whatsoever to atomic energy.

The next question that obviously hits us is what do we use for heat exchangers? How do we take heat from the reactor to the turbine which turns around and does useful work? It seems fairly clear that steam which we use in boiler plants is not going to be the answer. Steam at such high temperatures as will exist in reactors means very high pressures, which means in turn very large amounts of metal in the tubes which will carry it through the reactor, which again means that useful neutrons will be absorbed in undue quantities tending to dampen or stop the action of the pile.

Also, there is another requirement which does not enter into the design of the ordinary steam boiler, namely, that the heat exchanger shall not carry out into the plant itself any undue quantities of the radioactivity existing in the reactor — or, if it does carry such radioactivity out of the reactor, it will not in turn retransmit it to a possible second set of heat exchangers which would have to be placed between the reactor and the turbine. These requirements again narrow the possibilities to a few inert gases or some metals which are liquids at the temperatures we are talking about. In either case there are further questions of erosion or corrosion, and mechanical problems of the design of special pumps and seals to prevent contamination either of the circulating medium or the atmosphere around the plant. Such problems, again, are of an order which has been solved many times and which we can expect to be solved again.

There are other serious questions such as the reconditioning of fuel and disposal of radioactive waste products. In adding them all up, we have to conclude that there are too many unknowns in the equation to expect a solution at the first try. What must be done, it seems to me, is to get several coordinated groups to attack the problem from somewhat different points of view, come down to two or three possible designs, each one concentrating on some particular problem or design feature, analyze the contributions which each design has made and where it has failed, and then try again. Unless we are extraordinarily lucky on the first designs, a good operative nuclear reactor which will produce net useful power for any purpose will be achieved only through a series of approximations.

Perhaps I might illustrate what I mean by "several points of attack". Most of the thinking in this area goes toward the high efficiency and high temperatures which I mentioned. One of the groups, however, which has long practical experience in power plant design, believes that considerably lower temperatures than the ones suggested can be used without serious loss of efficiency in the plant. If this turns out to be true, several of the problems, while still formidable, will almost surely be of a somewhat lower order of difficulty.

Competition With Other Sources

Now, let us try to examine the second half of the question, which is that of economic competition with other methods of producing power.

It is a fair approximation to say that the cost of power from any source is made up of its capital cost, its operating cost, and depreciation or obsolescence. Hydro-electric power, as we know, normally has a high capital cost, a very small operating cost, very small depreciation, and since a good hydro-electric plant operates close to top theoretical efficiency, almost no obsolescence. A steam plant — and now we are talking about the boiler end of the steam plant, since the nuclear reactor as power producer is merely the boiler end of the plant — the steam plant has characteristically a low capital cost, a high operating cost (largely for fuel consumption), and a medium rate of depreciation or obsolescence which, since the initial capital cost is quite low, has little effect on the ultimate cost of power.

When we get to estimating the cost of power for atomic energy, we might as well admit at once that we are all at sea on each one of the major factors of cost. Until we have made a machine that will operate at all, we can't have any accurate idea of the capital cost. Any cost estimates based on the available scanty data would indicate that, at the beginning, the capital cost would be so high that even if there were *no* operating or depreciation factors, interest charges alone would take the atomic power plant out of competition with pres-

ent methods of power production.* This, however, should not be taken too seriously because, as soon as the first practical working prototype is in operation, the matter of capital costs can and will be seriously attacked. If previous history is any indication, good research development and engineering skill will effect radical reductions.

Next, as to operating costs of atomic power. Operating costs will probably be high in the first instance. Only the future can tell about the cost of fuel. If exploration for large deposits of uranium is successful, which is a reasonable hope, operating costs for fuel can be pulled down into the practicable range. This is a question which only time and effort can solve, and effort is being expended in search. Labor costs on nuclear reactors will tend to be high at first, but as we work from the experimental zone it should be lowered gradually.

When it comes to depreciation and obsolescence, we can expect to have very high rates at first and have no reasonable hope of expecting ever to get down to the low rates applicable to hydro-electric power production.

The heavy shielding required for protection against health hazards would seem to eliminate (in the present state of knowledge) any use of atomic power for small, mobile units. But for a use like that of ship propulsion, where the added weight of the plant might be more than offset by elimination of vast quantities of fuel for long voyages, atomic power looks quite promising. One would be inclined to guess that, at first, successful use might come for naval propulsion, where the ability to keep at sea for long periods without refueling might well outweigh higher unit operating costs.

For use on land, considering the weight and bulk of the necessary installations, a large reactor comparing in output with some of the largest central stations now being built would have the best promise of reasonable costs. Such a plant would come into direct competition with present sources of power. If it ever is to compete at all it is clear that where coal or its equivalent costs $20 a ton, atomic power will be used long before it will be considered in areas where coal costs $6. To try to look further ahead gets us more and more into a fog.

You have all seen and read statements upon the future of atomic power which sound very different from the one I have just given you. Some of them have come from sources which ought to know better. Others have just represented the blind trying to lead the blind, and still others apparently were done in the manner of the Buck Rogers comic strip which normally doesn't let a few facts stand in the way of telling a sensational story. We had automobiles running on a fuel supply the size of an aspirin tablet, ocean liners operating on a power plant that could be put into a suitcase. The reasons which make us believe that atomic energy is unsuitable for automobiles or any other small power use seem to be just as much facts of nature as the specific gravity, the melting point, or the color and odor of various chemicals and compounds. Unless we can develop a shield without weight or bulk for protection against radiation, atomic power plants for automobiles and the like are flatly impossible.

The Element of Time

At this time, I think I should recapitulate the story and leave it.

As I said in the beginning, the problem is first whether the nuclear reactor can produce net useful power at all. To that, I think the answer is "yes" and the time period is considerable — let's say five to 15 years.

Secondly, taking the answer to the first question as "yes", we do not know enough about any of the major elements of cost to be able to say flatly whether it will or will not compete with present sources of power. But, from the little we do know and what we can infer, we believe that it can fit, first in places where power costs are a minor factor, or where present power costs are very high. Anyway, my own guess is that it will — for many, many years — never do more than supplement *other* sources of power to supply what seems to be an accelerated growth in demand.

*Editor's Footnote — C. A. Thomas, vice-president of Monsanto Chemical Co., and (at the time) head of Clinton Laboratory's engineering staff at Oak Ridge, Tenn., prepared an estimate of comparative costs of a 75,000-kva. nuclear power plant and steam power plant located in eastern United States, and this was submitted on Sept. 5, 1946 by Mr. Baruch to the United Nations' committee on atomic energy. The proposed nuclear power plant was described in brief as a device to convert the fissionable energy of U^{235} to heat in a fluid which would power a conventional prime mover.

	Nuclear Power Plant	Steam Power Plant
First cost	$25,000,000	$10,000,000
Cost of fuel	?	$3.50 per ton at mine $7.00 per ton at boilers
Cost of power	0.8¢ per kw-hr.	0.65¢ per kw-hr.

In this same document, Mr. Thomas estimated that coal need only rise in price to $10.00 per ton at the boilers to raise the price of steam plant energy to that of nuclear plant, that is, 0.8¢ per kw-hr. From the reading of Mr. Pike's statements above, it might be surmised that Mr. Thomas's estimates were somewhat optimistic.

Supplement to

Metallurgy in America, 1917-1947

By The Editor

In last January's issue of *Metal Progress*, the Editor ventured to publish a list of "metallurgical milestones" witnessed since the organization of the American Society for Metals (1917). It was to be expected that this, as well as the "Critical Point" in the February issue on the same subject, would bring forth considerable criticism as to accuracy and completeness. That expectation has been fulfilled. This supplement, therefore, is an attempt to make desirable corrections and additions, and incidentally (it is hoped) to indicate some limitations which were necessary lest such a summary get entirely out of bounds.

The origin of the project explains some of the citations that appeared. It was planned originally for the previous October's issue, celebrating the Society's annual convention in Chicago. Hence the inclusion of many items of more importance to the Chicago region and to the ⚙ than to civilization generally. One example is the citation in 1917 to South works, Illinois Steel Co., Chicago, for first ingots cast from electric furnaces. This correctly states the fact that electric steel was 30 years old in the Chicago region, but does injustice to Halcomb Works of Crucible Steel Co. of America (Syracuse, N. Y.), where the late Richard S. Read cast the first heat of electric steel made in the U.S.A. in 1906. (See his biographical appreciation, *Metal Progress* for October 1946.)

The limitation of the 30 years, 1917 to 1947, of the review naturally excluded mention of many inventions of first importance, as was noted in the Editor's "Critical Point" in the February issue. It also, regrettably, excluded mention of one of the real pioneers in the furnace industry — American Gas Furnace Co. — whose list of "firsts", around the turn of the century, is imposing. Roller hearth furnaces (1899), rotary retorts for heating and gas carburizing (1902), nitriding (1908), automatic temperature control with millivoltmeters (1910) — such achievements as these richly deserved the Sauveur medal bestowed upon the company's long-time president, Adolph W. Machlet, in 1940.*

A similar injustice was done to Brown Instrument Co., whose founder, Edward Brown, made the first pyrometer to be manufactured in the United States (of the expansion type), and whose history for the past 89 years includes dozens of improvements in the details of measurement and control systems for heat and for fluid flow. Most of this firm's activities in the pyrometric field prior to 1917 had to do with instruments of the millivoltmeter type.

We must plead guilty of a couple of editorial lesions — wrong names. One especially causes blushes of shame, namely, the crediting of H. F. Moore (the eminent member of the University of Illinois's faculty) for work done by Thomas L. Moore (now assistant manager of the development engineering department of Rustless Iron & Steel) showing that the maximum hardness of quenched steels depends only on their carbon content. This 1938 publication, in collaboration with Messrs. Burns and Archer, appeared in ⚙ *Transactions*, and there is no excuse for not having verified the citation in *Metal Progress* against the original.

One comment that is perhaps more *a propos* to the "Critical Point" in February than to any of the citations on welding processes starting in 1918 was made by Merrill A. Scheil of A. O. Smith Corp., namely, that the real pioneering achievement of the 1920's was the welding of *ductile* joints in

*See biographical appreciation in *Metal Progress*, July 1941, p. 46.

structures. Mark up another one to the score of American engineers and technologists!

A friendly critic, who desires to remain anonymous because he has no desire to participate in a "chain-reaction of discussion", questions the item: "1938 — First commercial heat of boron-treated steels made at Wisconsin Steel Works", saying that literature references to the use of boron for steel date back at least to 1907, and that ferroboron made by Electro Metallurgical Co. "was used to spike openhearth and electric furnace heats in order to increase hardenability and to produce coarse-grained killed steel" prior to 1938 at Timken's steel plant. The Editor would say in reply that this item is an illustration of the difficulty of getting accurate information about an idea that is being actively exploited by more than one commercial concern, and on which the patent rights are still uncertain. The principals are vague or evasive. It will be noted that the citation made no mention of the *origin* of the idea.* It is also known now that boron was a constituent in commercial ferro-alloys used for increasing steel's hardenability prior to 1938, but it is the Editor's belief that nothing was said about the specific effect of boron by the producers of these complex ferro-alloys, even though it is quite probable that inquiring metallurgists and spectroscopists among the customers in the steel industry had well-founded suspicions and acted accordingly. Consequently, the year 1938 and the citation to Wisconsin Steel Works must stand until there is evidence that boron in controlled minute amounts was added as a hardener at some other plant, and the resulting steel was put into use with full knowledge of this fact by the consumer.

Somewhat similar considerations surround the situation concerning the use of oxygen as a smelting or refining reagent. With some difficulty it was ascertained that blowing the oxygen down in stainless steel heats became more-or-less routine practice in 1938 and that large-scale experimentation with oxygen in tonnage openhearth steels started in 1942. Hence the respective citations to Chelius and to Steel Co. of Canada in the original list. It now appears that injustice was done to Henry C. Bigge, superintendent of the toolsteel department of Bethlehem Steel Co., who applied for a patent in 1922 (No. 1,513,735 of 1924) covering the injection of oxygen under pressure into the bath of molten metal to reduce the carbon rapidly and to generate extra heat to facilitate the incorporation of the alloying metals. Consequently an appropriate citation is added in the adjoining list under year 1922.

Simple requests for information often brought material in great profusion. In two instances, so much was compacted in a single document that they warrant reprinting in full. First is from Prof. H. F. Moore, an outline of the studies on internal transverse fissures in steel rails, leading up to the controlled cooling in the rolling mills at Dominion Steel & Coal Corp. of Sydney, Nova Scotia, in 1931 — a process that is now all but universal in the United States as well. The second is a vivacious comment on the Editor's list of tentative entries for the brass industry written by D. R. Hull, assistant technical manager of American Brass Co. These two documents follow:

Rails Investigation

By H. F. Moore

IN 1911 a wreck, due to a broken rail, occurred on the Lehigh Valley R.R. near Manchester, N. Y. An investigation of the broken rail was made by the late James E. Howard, then chief inspector of safety appliances for the Interstate Commerce Commission. This was very nearly the first, if not actually the first, recognition of a type of fracture starting from the *interior* of the rail head where the incipient crack could not be detected by any means available at that time. Fractures of this sort soon became rather alarmingly frequent, and considerable study was given to these "transverse fissures", as such fractures were called.

In 1919 F. M. Waring and K. E. Hoffammann of the Pennsylvania R.R.'s laboratories at Altoona, Pa., presented a paper on "Deep Etching of Rails and Forgings" before the American Society for Testing Materials in which they described how, by deep etching of longitudinal slices of *new rails*, there were found cracks below the surface of the head in some of the rails. There was a brisk discussion of this paper, and opinion varied whether the cracks were due to the rolling and cooling process used for rails, or to the etching.

During the period of the first World War, and for some time before, it had been found necessary to cool slowly such things as steel wheels, heavy cannon or other forgings, and especially large machine parts of alloy steel, to prevent the development of "flakes" which showed a marked resemblance to the "shatter cracks" found by Waring and Hoffammann and in some rails broken in service. *(Turn to p. 830)*

*Not one of the items in this list of "milestones" but has a long ancestry of more-or-less closely related discoveries, suggestions, adaptations, attempts, patents. The historical situation concerning boron is fairly well known; see, for example, the articles in *Metal Progress*, October 1946, p. 677, and August 1947, p. 257.

Supplement to List Published in January

1917

(Revision of old items)

Continuous heat treating unit (hardening, quenching and drawing), the whole being automatically controlled by Bristol pyrometric equipment, built by Electric Furnace Co. for Sharon Works, National Malleable & Steel Castings Co.

First ingots cast from **electric furnaces** at South Works, Illinois Steel Co., Chicago. (Electric furnace toolsteel made since 1906 at Halcomb Steel Co. in Syracuse, N. Y.)

1919

(New citations)

American Welding Society organized.

Qualitative relationship between hardness and grain size of **alpha brass** shown by W. H. Bassett and C. H. Davis.

1920

(New citation)

Flame hardening used for hacksaw blades at E. C. Atkins & Co. in Indianapolis.

1922

(New citation)

Henry C. Bigge makes electric furnace heats of low carbon alloy and high speed steels using **oxygen to reduce carbon** in the molten bath.

1924

(New citations)

Work by Colin G. Fink, Marvin J. Udy, Horace E. Haring and William Blum led to commercial application of **chromium plating** for hard surfaces and for decorative purposes.

Pioneer gas analyzer introduced by Brown Instrument Co. — an electrical indicating and **recording CO_2 meter.**

1925

(Revision of old item)

Batch-type furnace with gas atmosphere recirculated by fans (from heating elements through work) built by Leeds & Northrup for Greenfield Tap & Die Co.

1926

(New citation)

D. J. McAdam began his extensive publications on **corrosion-fatigue.**

(Transferred from 1929)

W. L. Fink and E. D. Campbell demonstrated that **martensite** has a body-centered tetragonal structure.

1927

(Revision of old item)

Flame hardening of rail ends to resist wheel batter applied to mainline trackage on Erie and Milwaukee railroads.

(New citations)

Systematic study of **dispersion hardening of copper** alloys having variable alpha range by heat treatment (Cu-Si, Cu-Cr, Cu-Co, and ternary alloys with Si) published by Michael G. Corson.

Welding process using **separately applied clay flux** invented by Boris S. Robinoff, Sumner E. Paine and Wrignel E. Quillen.

T. R. Harrison of Brown Instrument Co. designed instrument for continuous recording and remote **control of liquid level and flow.**

1930

(Replace item on submerged arc welding with:)

Shielding of arc, when welding aluminum and stainless steel, with inert gas such as helium or argon, patented by Henry R. Hobart and Philip K. Devers, respectively.

(New citation)

"Protectoglo" developed by Minneapolis-Honeywell — an electrical circuit from hot electrode to flame which closes fuel valves if flame is extinguished.

1931

(New citation)

First of a series of publications on **Widmanstätten structure** and early stages of age hardening by Robert F. Mehl and associates.

(Revision of old item)

Continuous **gas carburizing,** using natural gas diluted with partially dried flue gas, started in Chrysler Corp.'s Newcastle plant (Surface Combustion equipment).

1932

(New citation)

Submerged melt welding process using greatly increased currents invented by L. T. Jones, H. E. Kennedy, and M. A. Rotermund.

1934

(Corrected name in old item)

Carbon control of axle shafts during hardening by adjusting H_2O and CO_2 to steel's carbon content (Holcroft & Co.'s furnace in Dodge automotive plant).

1935

(New citation)

Automatic optical pyrometer system devised by Brown Instrument Co. for continuous recording of temperatures in rolling mills.

1937

(New citation)

Frank R. Palmer published **"Tool Steel Simplified",** containing Carpenter Steel Co.'s system of a matched set of toolsteels.

1938

(Corrected name in old item)

J. L. Burns, Thomas L. Moore and R. S. Archer demonstrate that the hardness of fully-quenched **martensitic steel** depends upon its carbon content only.

(New citations)

Inhibited admiralty metals (As, Sb or P added to resist dezincification) introduced; phosphorized admiralty tubes offered by Scovill Mfg. Co.

Julian M. Avery proposes to increase blast furnace capacity and coke efficiency by **increasing the "top pressure".**

1939

(New citation)

Tempering of martensite analyzed in extensive studies by Morris Cohen and associates.

1941

(New citation)

Descaling by sodium hydride dissolved in molten caustic soda (process developed by H. N. Gilbert of DuPont's electrochemicals department) commercially applied.

1942

(New citation)

Rotating regulators for controlling electrode positions installed by Allis-Chalmers Mfg. Co. on arc furnace at Sharon plant of National Malleable and Steel Castings Co.

1944

(New citations)

ASM starts Review of Metal Literature.

C. Zener and J. H. Hollomon demonstrate equivalence between temperature and **strain rate** necessary to produce a given stress in metals.

1946

(Revision of old item)

Periodic reverse current, to deplate any prior inferior electrodeposits while building increments of sound metal, devised by George W. Jernstedt of Westinghouse Electric Corp.

(New citation)

Institute for the Study of Metals formed at University of Chicago.

In the later years of the 1920's I. C. Mackie, engineer of tests of the Dominion Steel and Coal Corp. of Sydney, Nova Scotia, having noted the beneficial effects of slow cooling on wheels and forgings, began a series of experiments of *rail* cooled on the ordinary hot beds, and on other specimens slowly cooled in heat-insulated boxes. These "control-cooled" rails were cooled in the open air down to a temperature *well below* the critical range for rail steel. Rails had usually been cooled in air down to about 900° F., and Mr. Howard found that a considerable number of the rails cooled on the hot bed showed shatter cracks, whereas the control-cooled rails did not. Mr. Mackie was careful to cool the rails slowly down to nearly atmospheric temperature.

In 1931 Mackie devised and put into use (in the Dominion steel mills at Sydney) cooling boxes and other equipment for control-cooling of rails, and a little later such a process was put into operation at the Algoma steel mills at Sault Ste. Marie. The control-cooled rails from these mills did not develop transverse fissure failures in service, and they were becoming quite common on the Canadian railroads in the early 1930's.

In the last years of the 1920's — 1929, to be exact — an investigation of transverse fissures was started at the University of Illinois in Urbana under the sponsorship of the Chicago Elevated Railroads. For that investigation there was developed a testing machine (known as a "rolling-load" machine), in which a short length of rail was pushed and pulled back and forth under a stationary wheel which could be loaded up to 50,000 lb. (See *Metal Progress*, November 1935, p. 47.) Under such repeated loads as low as 40,000 lb. transverse fissures were developed in some, but not in all, rails in which etch tests had shown shatter cracks. In no case was a transverse fissure produced in a rail in which the etch test had showed no shatter cracks. All rails so tested were new rails, never having been in track.

In the discussion of the Waring and Hoffammann paper on deep etch tests, J. E. Howard emphasized the high localized stress developed at the contact of rail with steel. He emphasized that the high surface stresses were compressive, as shown by the famous analysis of Hertz. In the investigation of rails at the University of Illinois, Prof. V. A. Hoersch and H. R. Thomas developed the Hertz analysis so as to determine stresses, not only at the contact surface of rail and wheel, but also in the steel *below* this region of contact. As their work was nearly finished it was found that there was printed in Russian an analysis by N. M. Belajef, which appeared a year or two before. The two analyses checked in all points. Hoersch and Thomas verified their results by special strain-etch methods, and devised nomographic diagrams to solve the difficult equations of the mathematical analysis. They found that the dangerous stresses were tensile and shearing stresses developed below the surface of the rail, and that under a wheel load of 40,000 lb. (making allowance for the stress intensification at the end of a shatter crack) the stresses developed were slightly greater than those at the endurance limit developed in tests of rail steel under bending, repeated, but not reversed.

In 1931 this investigation became a part of a more extensive investigation at the University of Illinois which was sponsored jointly by the Association of American Railroads and the Technical Committee of the Rail Steel Manufacturers. Quite early in this larger investigation, and by statistical analysis of observations of some 500,000 recording strain-gage locations on rails in actual service on four railroad systems, it was judged probable that any point in a rail might be subjected to a 40,000-lb. wheel load about once for every 500 wheel loads passing over it.

Rolling-load tests of control-cooled and hot-bed-cooled rails from many mills were continued in this larger investigation, and freedom of control-cooled rails from transverse fissure failures continued to be the rule with scarcely an exception. In the early part of this extensive study, Mr. Mackie gave the investigators valued assistance in furnishing from the Algoma mill companion pairs of rails from a heat — one control-cooled, the other hot-bed-cooled. About 1935, rail mills in the United States began to install controlled cooling equipment for their rails, and today nearly all rails rolled are control-cooled. These control-cooled rails have developed very few transverse fissures in service.

A long series of tests was made by the Illinois test parties at various rail mills on the range of temperature and the maximum allowable rate of cooling if shatter cracks in rails are to be avoided. In making these tests it was highly desirable to have a source of test rail specimens in which it would be sure that under hot-bed-cooling shatter cracks *would* develop. This was brought about by a daring process developed by H. B. Wishart at the Gary rail mill and used at that mill and others by R. E. Cramer, the metallurgist of the Rails Investigation. In one ingot of a heat, dry hydrogen gas was blown into the molten steel as the ingot molds were filled. Steel from these ingots caused a large number of shatter cracks in hot-bed-cooled rails, *but there were found no shatter cracks in the control-cooled rails* from the same ingots!

The present code requirements for tempera-

tures and cooling rates for control-cooled rails are based on the results of these tests. In this connection, also, Mr. Mackie was of great assistance to the Rails Investigation, in that he obtained permission to allow the University test party to treat molten steel with hydrogen at the Sydney mills of the Dominion Steel and Coal Corp.

The Rails Investigation at the University of Illinois is still in progress, although (for the most part) other types of rail failures are now studied. That investigation was under the direction of Prof. H. F. Moore until his retirement in 1944. Since that time it has been under the joint direction of Prof. R. E. Cramer and Prof. N. J. Alleman. Since Professor Alleman's decease R. S. Jensen has taken over his work. In connection with this investigation special mention should be made of the valuable work of Prof. H. R. Thomas, Prof. N. H. Roy and Messrs. J. L. Bisesi, H. B. Wishart, S. W. Lyon and E. C. Bast, and of the excellent advisory committees of the Association of American Railroads and of the technical committee of the Steel Rail Manufacturers.

Milestones in the Brass Industry

By D. R. Hull

It is astonishing to notice how seldom a milestone or even a landmark has appeared, full fledged, from the brain of a Jovian genitor. Most of the things the brass mill has are the result of such slow and painful growth that it would be difficult to date their beginnings. Even when this can be done, it usually precedes, by a good number of years, the first public announcement of it. In the following comments, therefore, I am not being iconoclastic, but am merely pointing to the earlier account of such items as some of the old-timers here happen to know about.

1917 — While this was the date of the publication of Mathewson and Phillips' systematic study of recrystallization in alpha brass, the relation of grain size to annealing temperature had been quite thoroughly worked out by 1910 and was in use in the mills of American Brass Co., at least. The microscope had long been in use for the study of steel and minerals and was adapted to the brass industry at least as early as 1905. It detracts nothing from Mathewson and Phillips if we consider their paper as a culminating expression of the work of the preceding 20 years. (In those days it was not the policy of brass mills to hurry in the publication of their work!)

1929 — Your citation of electrolytic zinc of extra high purity for die casters is important, but it seems to us that the real milestone was the development of electrolytic zinc by Anaconda Copper Mining Co. about 1920, and that the high-purity zinc for die casting was a specialized development of the general electrolytic process.

1931 — Bright annealing of copper tubes. The old Benedict and Burnham Branch of American Brass Co. had a continuous Bates and Peard bright annealing furnace in 1905. Whether or not the idea was new at that time, it has been in continuous agitation at various brass mills ever since. We would agree, however, that the sudden and quite universal transition from oil-fired furnaces to modern gas-fired annealing furnaces which took place in the early 30's was a significant part of a general trend. It was as great a transition as the one from wood-burning muffles to oil burners, which was in full swing about 1910.

1932 — Even oxygen-free, high-conductivity copper, epochal as it was, had an antecedent. Cyril Stanley Smith used to take pleasure in digging up such things, and once came up with Dr. J. Percy's "Metallurgy", edition of 1861 (British), in which were expounded the principles on which OFHC is based.

1935 — Concerning your citation of free-cutting tellurium-coppers, selenium-copper and tellurium-copper were being worked on in 1933. Patents for the former were obtained by Cyril Stanley Smith for American Brass Co. and the latter by D. E. Lawson *et al.* for Chase Brass & Copper Co. Neither of these alloys has found very wide use. The old-fashioned leaded copper is quite free-cutting and is generally preferred.

1936 — I think it is fair enough to give American Smelting and Refining the credit for continuous casting. They really made it work. It was an important accomplishment, although the idea was old. I very well remember advertisements, with pictures, of a continuous rod casting machine, in the *Brass World*, about 1912 or 1913, but cannot recall the name of the promoter. [Editor's note: Bridgeport Brass Co. was working with the so-called Eldred process in 1933 and made some ¾-in. round copper rod, and Scovill Mfg. Co. in 1934 continuously cast 6-in. rounds of cupronickel. In 1938 Scovill went into production of copper-base alloys by the Junghaus process of continuous casting.]

1945 — The citation to Naval Gun Factory for using potassium nitrate to aid in casting pressure-tight articles of phosphor bronze is questionable. In the *Proceedings* of the American Institute of Metals for 1914, it is recorded that, at the autumn meeting held in Chicago, a man named Schwartz advocated the use of saltpeter for improving the soundness of his castings. In the middle 20's Paul D. Merica devised and patented a method for burning carbon and hydrogen out of his nickel-

copper alloys by oxidation. In the early 30's Henri Lepp patented and widely broadcast a method for making tin bronzes with an oxidizing slag. More recently Pell-Walpole has published a great deal on the same subject. The nonferrous industry must have been generally aware of this treatment since around 1930.

Many more of the items queried are quite difficult to pin down with a very accurate date:

Tube Extrusion (in contradistinction to extrusion of solid rods) — The idea is certainly very old, but like so many other things had to await the development of suitable steels before it could "come of age". The American Brass Co. set up a Schloemann press for tube extrusion in 1931. (It is still in use.) This press was imported from Germany, which would imply that the process was much more advanced there than it was in America. [Chase extruded tubes in 1934. Scovill's 1100-ton vertical Schloemann press started production of extruded tubes in 1936.]

Aluminum Brass Heat Exchanger Tubes to resist impingement attack were of British origin (1928) and the first aluminum brass condenser tubes sold in America in the late 20's were imported [trade name "Yorcalbro"]. I do not believe any brass mill in this country can take credit for them, but believe their manufacture was started by various American producers shortly after this time.

Cupro-Nickel Tubing — Benedict and Burnham plant was making 85-15 cupro-nickel tubes by the Mannesmann process in 1901 and advertising them in its price list. It first made cupro-nickel and admiralty condenser tubes by the cupping process in 1907.

Beryllium-Copper — The discovery of the precipitation hardening properties of beryllium was made in Germany and no one in this country can take any credit. The *control* of those properties through the addition of nickel was patented by Silliman for American Brass Co. in 1934. Most of the beryllium-copper has been made under the Silliman patent, but the Beryllium Corp. of America uses cobalt, under another patent.

General Mill Practices — Although it came in a little more than 30 years ago, the Ajax-Wyatt low-frequency melting furnace was the greatest single upheaval in brass metallurgy that has occurred in our day.

The sudden and almost universal change from cast iron molds to water-cooled molds during the late 30's was a major transition. Water-cooled molds had been known and used for a long time in Europe. They found little favor in this country until the trend to heavier castings created a need. Then their adoption was swift.

It is true that the brass industry is now in the midst of a revolution so profound that we who are involved have difficulty in realizing its full scope. It is a revolution of *equipment*. The 4-high rolls, the Steckel mill, the Sendzimir mill in prospect, the much heavier castings with mechanical handling throughout the mill, the roll conveyer, the improved annealing furnaces, piercing machines, extruding machines, drawbenches — all add up to something profoundly significant, but there is scarcely one of them that can pretend to be anything but an improvement on what went before.

National Officers Nominated

IN CONFORMITY with Article IX of the Constitution of the American Society for Metals, the duly accredited nominating committee met in Columbus, Ohio, on May 19 and made the following nominations for national officers of the Society:

HAROLD K. WORK, for President for one year.

ARTHUR E. FOCKE, for Vice-President for one year.

HARRY P. CROFT (Cleveland Chapter) for Trustee for two years.

FREDERICK J. ROBBINS (Los Angeles Chapter) for Trustee for two years.

Also, according to the Constitution, Article IX, the committee for nominating a secretary was composed of the president (F. B. Foley), chairman, and the six persons who most recently held the office of president, namely, A. L. Boegehold, C. H. Herty, Jr., K. R. Van Horn, M. A. Grossmann, H. J. French and Bradley Stoughton. This committee has made the following nomination:

WILLIAM H. EISENMAN, for Secretary for two years.

Article IX on the nomination, election and term of officers also contains the following:

Section 1 *(c)* **Additional Nominations.** After publication of the names of the candidates nominated by the Nominating Committee and by the Committee for Nomination of a Secretary for the Society, if any, and at any time prior to July 15th of the same year, additional nominations for any or all of the vacancies may be made by written communications addressed to the Secretary of the Society and signed by any fifty (50) members and/or representatives of member firms or corporations.

(d) **Voting at Annual Meetings.** If no such additional nominations are received prior to July 15th, nominations shall be closed and the Secretary, at the next succeeding annual meeting of the members, shall cast the unanimous vote of all members for the election of the candidates so nominated.

During a study of gas-metal systems being conducted for the Office of Naval Research, the author has discovered further evidence for the theory that scale is blasted away from metal by bubbles of hydrogen issuing from within the metal, and under high pressure.

Electrolytic Descaling

By Carl A. Zapffe
Consulting Metallurgist
Baltimore, Md.

PARTICULARLY in Europe, the electrolytic descaling and cleaning of metals has attained some industrial importance, and there are those who believe that it is indicated for a much wider development in this country.

In reviewing previously stated theory on the mechanism of the descaling action in the cathodic cleaning of steel (electrolytic descaling), one finds the common belief that the electrolyte first penetrates voids and capillaries in the scale structure, then dissociates electrolytically at the underlying metal-scale interface, and finally blasts off the surrounding scale through aerostatic expansion of the hydrogen gas that is produced.

This theory is unsatisfactory for two reasons: First, a breach of logic is indicated in supposing a liquid to be able to enter a void or crack under normal pressures through which a gas cannot subsequently exit, and whose pressure is sufficient to rupture tightly adhering scale. Second, it ignores a known pressure-function of hydrogen dissolving or dissolved in steel, by which rupturing forces of very high magnitudes are attained.

The Planar-Pressure Concept — Conditions of cathodizing readily lead to the dissolving of hydrogen in steel. (In cathodizing, of course, the metal is connected to the negative side of a direct-current circuit and immersed in an electrolyte — that is, made the cathode.) Hydrogen, entering the steel atomically, is known to precipitate rapidly as molecules within any void large enough to allow evaporation of the atom from the iron lattice. Fundamental thermodynamic relationships then indicate that great gas pressures can develop within the void. These same remarks are true for acid pickling.

Here, however, contemporary writers continue to restrict their attention to voids on the microscopically visible scale of inclusions, cracks, and possibly grain boundaries. That restricted concept principally concerns such a phenomenon as blistering, and it is certainly incomplete. Because of the minuteness of the hydrogen atom, mere looseness among the crystalline lattice planes of the host atoms provides sufficient void, and such looseness is now becoming recognized as a general characteristic of all crystals larger in dimension than a few atom diameters. It is this looseness which gives rise to the fracture patterns observed in all fractographs, such as the ones reproduced excellently in *Metal Progress* in its issues for Aug-

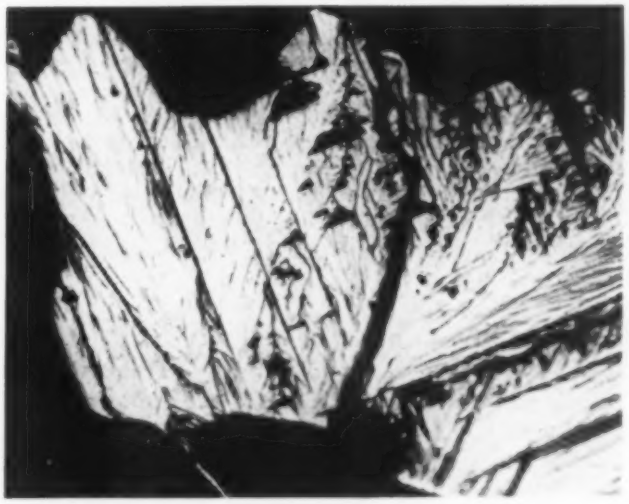


Fig. 1 — Fractograph of Embrittled Armco Iron; 250×

This is a single grain, the grain boundary showing as a profile at top edge. Latticular looseness, involved in hydrogen embrittlement, shows as a geometric pattern of quasi-defects along crystallographic planes.

ust 1946 (p. 283), March 1947 (p. 428), and March 1948 (p. 377).

A good instance is shown in Fig. 1, one of a group used for "A Micrographic Study of the Cleavage of Hydrogenized Ferrite" by C. A. Zapffe and G. A. Moore, published in *Transactions* of the American Institute of Mining and Metallurgical Engineers, V. 154, 1943, p. 335. This particular specimen is Armco iron, purified by treatment in hydrogen at 1000° C. (1830° F.) and subsequently embrittled by a 30-min. cathodic treatment in 5% H_2SO_4 at 0.05 amp. per sq.in. Since the embrittlement is transgranular, the phenomenon does not involve the grain boundary (which shows as a facet profile at the top of Fig. 1). Nor does it directly involve other major discontinuities, such as the void visible within the grain at the terminus of the large fissure.

Instead, it involves subtle weaknesses in the

Fig. 2 — Fractograph of Neumann Band in 4.24% Silicon Ferrite; 3000×

A lamellar outcropping believed to depict the inherent imperfection structure of the crystal. Note the uniformity in the thickness of the platelets. Latticular looseness between such platelets is believed to be directly involved in the precipitation of hydrogen during the process of embrittlement.

crystal lattice, here showing as crystallographic deformation markings and tiny rectilinear voids where blocks of the lattice have broken out during fracture. These quasi-defects belong to the crystal symmetry, and are referred to here as "planar imperfections". They are apparently an inherent feature of all real crystals, as distinguished from ideal crystals.

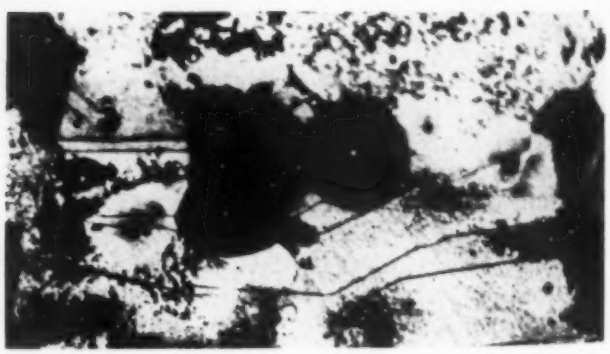
Consequently, all metals under discussion comprise crystals whose inherent mechanical architecture allows the pressure function of dissolved hydrogen to operate as a general phenomenon, with or without contribution from grosser openings. Because of the crystallographic characteristics of planar imperfections, the general concept has been referred to in a paper by the author before the Iron and Steel Institute (Great Britain) in 1946 as the "planar-pressure theory of hydrogen embrittlement".

While the general theory for the planar-pressure phenomenon was developed some years

Silicon Ferrite, 200 ×

Fig. 3 — Tiny Bubbles of Hydrogen Escaping From Metal and Trapped Below Oil Film

All bubbles appeared suddenly and without further growth, and only over deformation markings, whether Neumann bands or slip. Deformation either before or after hydrogenizing produced similar results, proving the inherent presence of latticular looseness, the occlusion of hydrogen at those sites, and the location of deformation movements along the sites.



Armco Iron, 500 ×

ago by the present author in collaboration with C. E. Sims,* the paper just cited before the British Institute demonstrated for the first time both the existence of these intrinsic latticular discontinuities or voids and the occlusion within them of

*"Hydrogen, Flakes, and Shatter Cracks", *Metals and Alloys*, V. 11, 1940, p. 145, 177; V. 12, p. 44, 145. "Hydrogen Embrittlement, Internal Stress, and Defects in Steel", *Transactions*, American Institute of Mining and Metallurgical Engineers, V. 145, 1941, p. 22[illegible].

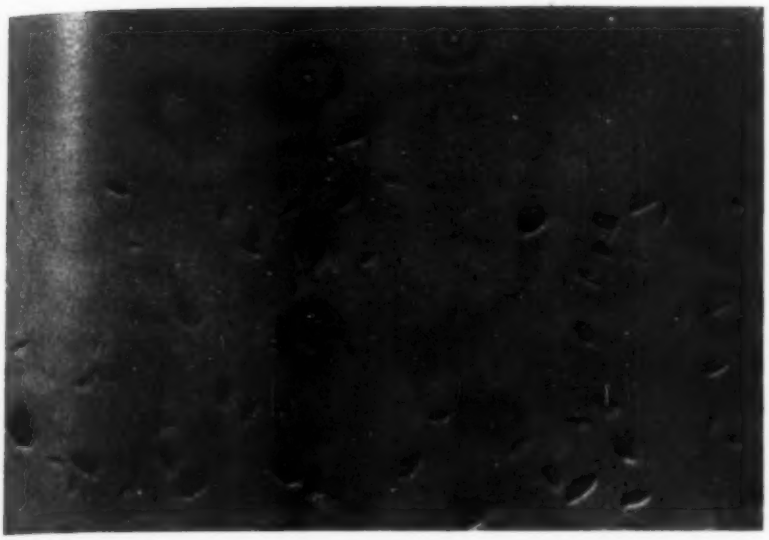


Fig. 4 — "Descaling" Activity of Occlusion-Diffusion Mechanism; 2×

Sulphuric acid worked through pores and cracks in a vitreous-enameled laboratory pan and attacked the underlying steel. Hydrogen released by the acid-metal reaction dissolved atomically into the steel, presumably precipitated into intracrystalline openings under high pressure, and these occlusion pockets then blasted their way to the surface, exploding away chips of enamel as the gas escaped.

hydrogen under high pressure. A fractograph in Fig. 2, at a magnification of 3000, gives a more detailed view of the voids in question, showing a surprisingly regular outcrop of thin lamellae along the slope of a Neumann deformation band in silicon ferrite. In Fig. 3 a burst of occluded hydrogen is captured beneath a superficial oil film as the tiny volume of gas escaped from a Neumann band in silicon ferrite. The lower view shows a similar escape from a deformation marking in Armco iron.

In these experiments there were two sets of conditions. In one, deformed metal was hydrogenized. In the other, annealed metal was hydrogenized and subsequently deformed. In both the hydrogen effused in sudden bursts of substantially equal amounts, and always from a deformation marking, whether Neumann band or slip. The tests therefore proved simultaneously *(a)* the occlusion of gas within minute latticular voids, *(b)* the pre-existence of these voids in normal or unstrained crystals, and *(c)* plastic movement along these voids.

The Occlusion-Diffusion Concept — Within the planar imperfections of each crystal, atomically dissolved hydrogen precipitates and develops pressure sufficient to blast a path from one to another. In that way the gas travels through the metal along the same planar imperfections which seat plastic deformation. Its travel is considerably more rapid than if dependent on diffusion through the perfect lattice, atom by atom. We can refer to the action as "occlusion-diffusion".

Where these paths of occlusion-diffusion emerge at a scaled-over surface, as during cathodic descaling (and probably similarly during acid pickling), the pressure of the emergent gas is of the order of the strength of the steel and is therefore ample to blast off any overlayer. The action is well exhibited in the fish-scaling of vitreous enamel, synthetically reproduced in Fig. 4.

The Descaling Mechanism — To demonstrate the action specifically for cathodic pickling, a strip of mild steel was fired smoothly with vitreous

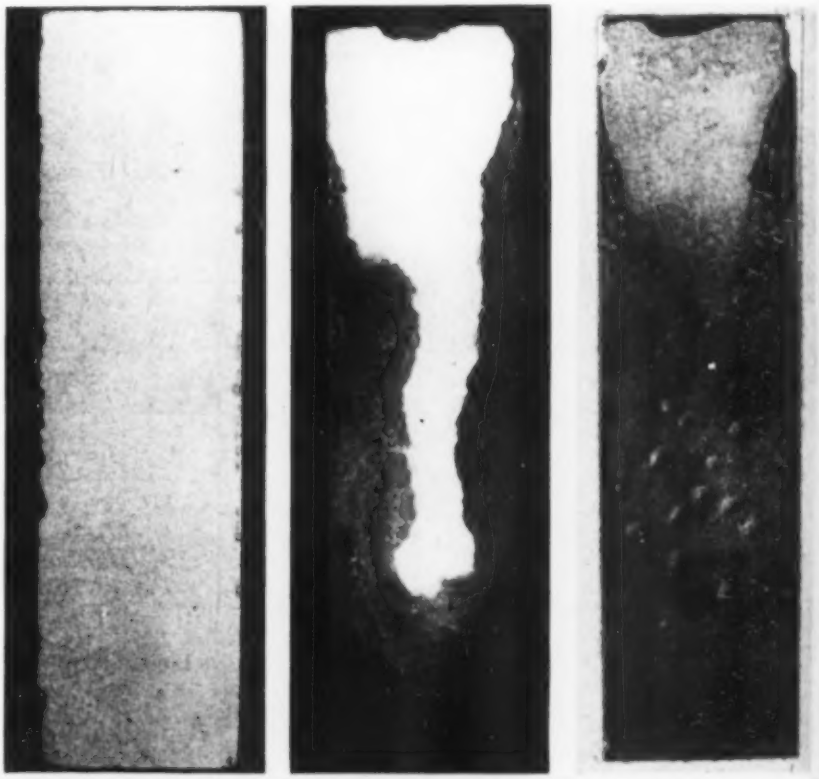


Fig. 5 — Three Stages in "Descaling" of Enamel, Continuous Except at Edges

A thin steel strip, smoothly fired with vitreous enamel, showed no permeability of its surface by electrolyte. Its sides were then carefully exposed by filing. Immersed as cathode in 1% H_2SO_4 at moderate current density, the strip absorbed hydrogen at its edges. The gas entered the steel, developing latticular occlusions of molecular hydrogen under high pressure. These compressed occlusions forced a path to the adjoining surface underneath the enamel and blasted it away. Descaling has thus been accomplished by hydrogen which first dissolved in the metal. Note the blisters in the steel, giving evidence of high hydrogen pressures.

enamel. When placed in an electrolytic circuit, this strip allowed no current to pass, thereby proving the absence of liquid-permeable pores in the enamel. Its edges were then carefully cleaned bare of enamel, exposing the steel, and the strip was immersed in a 1% H_2SO_4 solution. Current was immediately passed at an initial density of about 5 amp. per sq.in., calculated for the area of the exposed metal at the edges.

In Fig. 5 this strip is shown in three stages, original, partly descaled, and fully descaled. Descaling progressed, as is evident, only from the seats of hydrogen absorption — here, the edges. The fact of absorption is clearly proved by the blisters remaining on the steel at completion of the test. The action has been purely mechanical; the scale fragments detached explosively and simultaneously with a pronounced effusion of bubbles. Note that the more severe action has occurred at the lower end where hydrogen infiltrated from three sides.

As for the mechanism believed to be involved, Fig. 6 shows hydrogen entering the metal lattice as atoms at exposed areas, in keeping with accepted gas-metal theory; the subsequent behavior of these atoms is in accord with the planar-pressure activity just described. That is, the atoms immediately proceed to precipitate as molecules within the slender subcrystalline openings which are apparently available as a vast pattern throughout every grain, and indicated diagrammatically as such in the sketch. While this is the "mosaic structure" postulated by numerous physicists, and proved to exist by the tests just described, its description will be attempted in a series of papers being prepared in this laboratory detailing a new theory for the solid state. Figure 6 therefore is diagrammatic in purpose and does not purport to show the exact conformation of the planar discontinuities.

Essentially, the actions observed experimentally indicate that these occlusions of compressed hydrogen diffuse along the planes of crystalline symmetry, the gas pockets breaking from one domain into another and thereby attaining an appreciable rate of movement. (This speed has long been utilized in practice for the toughening of embrittled metals by very mild heating — sufficient only to increase the gas pressure and force the passageways.) The movement of these gaseous occlusions to surfaces underlying scale adjacent to the absorption areas blasts off, or initiates blasting, the overlying scale. The concentration gradient in the system, incidentally, is such as actually to lead the gas to coated portions of the metal, since the rate of infusion at bare areas is quite high, and at scaled areas it is zero. Furthermore, there is a mechanical expansion factor having a similar effect, for the crystal itself expands under embrittling pressures.

In summary, the first step in the descaling operation is one of absorption of hydrogen by the metal — a diaphragm-type action giving the gas its blasting potential. Descaling occurs when a portion of this highly compressed gas returns to the surface at an adjacent area beneath scale.

Even though the present mechanism is only given auxiliary status here as a new aspect of the descaling mechanism, some question might be raised as to whether the conventional theory of cathodic cleaning has any real importance. Likewise, the same application can be made to the theory of acid pickling, except that under those conditions the occlusion-diffusion mechanism must be auxiliary to chemical solution of scale underlayers.

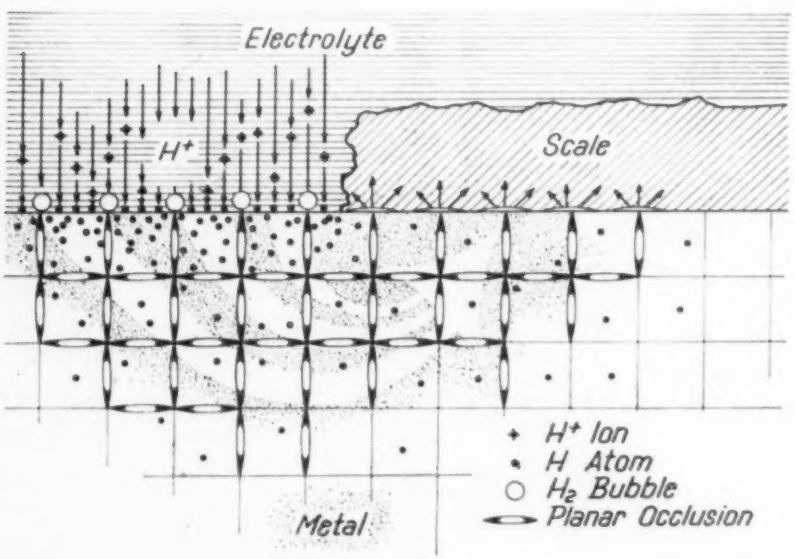


Fig. 6 — Sketch of Descaling Mechanism

Hydrogen atoms enter at areas of exposed metal at left, diffusing into the lattice. They shortly precipitate as molecules within a vast pattern of inherent imperfections within the grains. This gas, when attaining sufficient pressure, distends the latticular looseness into the condition of a discrete occlusion (embrittlement), and then forces a path from domain to domain. Those occlusions reaching the surface beneath contiguous scale blast the scale away. Others may return to the bare area through local connecting rifts and leave as bubbles; these are probably the "persistent bubbles" sometimes noted by electroplaters as always issuing from the same spot. The sketch, of course, is largely diagrammatic and does not purport to disclose the actual design of the imperfection pattern.

International Control Bogs Down

ON APRIL 5 the United Nations' Atomic Energy Commission accepted by vote of 9 to 2 (the Soviet Union and the Ukraine in the minority) a report from its "working committee" which had been considering the U.S.S.R.'s control proposals* since their submission on June 11, 1947. Verbatim extracts follow†:

The powers provided for the International Control Commission envisaged by the Soviet proposals‡ are confined to *(a)* "periodic inspections", and *(b)* "special investigations" which can be conducted only in the case of suspicion. The Soviet representative argued that continuous inspection over any one operation "would become supervision or management", yet could not show that periodic inspections could estimate the amount of material in process or the amount that has entered or left the plant [or mine] between inspections. The inspectorate would not be in a position to verify the entries appearing in the books. Therefore, it could not prevent diversion of the nuclear material.

"The Control" cannot detect or prevent clandestine activities. The "special investigations" can be carried out only when "suspicion of violation arises", but inspection is restricted in such a way that there would be no opportunity for "the Control" to become suspicious. For example, the Soviet refuses control over exploration for uranium or thorium ores and refuses inspection of related activities (such as production of heavy water or diffusion barriers) which would constitute strong presumption that atomic energy production was also being planned. Since the Soviet proposes "unrestricted scientific research in the field of peaceful uses of atomic energy", and the Soviet representatives gave no answer to the crucial question as to who would report irregularities in the work of these research laboratories, there appears to be no limit to the clandestine activities that may take place in laboratories ostensibly devoted to peaceful work.

Any international organization must be able not only to detect violations but also to prevent and correct them. The only other powers specifically provided for "the Control" are *(a)* the power to make recommendations to governments on production, stockpiling and use of atomic materials and atomic energy and *(b)* the power to make recommendations to the United Nations Security Council on measures for prevention and suppression in respect to violations of the conventions on prohibition or control.

It is agreed that such powers have no compulsory character; "the Control" has no mandatory powers. Even the slightest misdemeanor would have to be referred to the Security Council with, at best, inevitable delays. Whatever the ultimate action taken in case of a violation, it is vitally important that *immediate* action be taken to stop it, but even if periodical inspection detected violations, "the Control" would have no right to set guards or shut down the plant. The Soviet Union's insistence in reserving to the Security Council all actions pertaining to violations is another reason why its proposals cannot be accepted as the basis of a system of control.

The Soviet government requires that the prohibition and destruction of atomic weapons should take place *before* the conclusion of a second and separate international agreement to enforce that prohibition by an international control system. Past conventions "outlawing" various forms of warfare contained no provisions for their enforcement, and consequently remained expressions of hope and no more. Such a preliminary convention on prohibition, standing alone, could give no assurance *(a)* that nations known to possess atomic weapons would destroy all — or indeed any — of them; *(b)* that nations not known to possess them, but who might have them, would carry out their obligations; and *(c)* that nations would be prevented from manufacturing atomic weapons in the future.

The Soviet representative was asked whether there would be any assurance, once the prohibition and destruction of atomic weapons were effected, that the second agreement on future control [of fissionable materials] would ever come into effect. The reply was that "if there is found no basis for agreement, then, naturally, the convention cannot be concluded".

The working committee therefore finds that the Soviet proposals ignore the existing technical knowledge of the problem of atomic energy and the elimination from national armaments of atomic weapons, and therefore do not conform to the terms of reference of the Atomic Energy Commission.

[Since the American proposals have already been studied exhaustively and reported upon, and "have not the slightest chance of forming a basis on which to reach an agreement", in the words of Vassily Tarasenko, the Ukrainian representative, the attempt to establish international control appears to be at a dead end. On May 17 the entire United Nations Atomic Energy Commission voted to suspend further work toward international control of atomic energy, and to hand over the unsolved problem of bringing the U.S.S.R. and U.S.A. into agreement to the General Assembly of the United Nations, meeting in Paris this fall.]

*Outlined in *Metal Progress*, August 1947, p. 251.

†Complete text of the report is contained in *Bulletin of the Atomic Scientists* for May 1948.

‡For brevity, hereinafter called "the Control".

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

In this, the last of a four-part article on "The Eight Forms of Corrosion" (a chapter for the forthcoming third edition of "The Book of Stainless Steels), Dr. Fontana discusses one of the most puzzling and hard-to-handle manifestations.

Stress-Corrosion and Corrective Measures

STRESS-CORROSION is the general term describing corrosion accelerated by internal stresses or externally applied stresses. The stresses are sometimes complex, but *tension* stresses are generally if not always required. High internal or residual stresses are often produced during the forming of the part, by heat treatment, or other means such as locked-in stresses resulting from welding.

In practically all instances, stress-corrosion manifests itself in the form of cracks without appearance of ductility. Accordingly, this phenomenon is also designated "stress-corrosion cracking", although the word cracking is superfluous. If the stresses are fluctuating or cyclic in nature, the failure is often described as corrosion-fatigue — it being well known that the endurance of a metal part is reduced by corrosive surroundings.

Two of the earliest recognized instances of stress-corrosion, and perhaps the most widely known, are the so-called season cracking of brass cartridge cases, and the caustic embrittlement of steam boilers. Since brass cartridges were first made, great numbers have failed during storage in arsenals; many difficulties were also experienced in the last war. Stationary and locomotive boilers without number have failed or required extensive repairs because of stress-corrosion. The cause has been the subject of many investigations but no completely accepted mechanism for this form of corrosion has been proposed to date.

In general, stress-corrosion for a given material depends upon three factors, namely, the stress, the concentration and nature of the corrosive environment, and the temperature. If one of these factors is present in a high degree, such as high stress or high temperature, the other two factors could be very mild in nature for damage to result. For example, cold drawn or spun brass parts or dishes, containing high residual stresses, sometimes crack when exposed to ordinary atmospheric conditions, especially when a slight amount of ammonia or amines is present. (In fact, ammonia and amine-containing atmospheres are used as tests for susceptibility of brasses to stress-corrosion.) As another example, the tendency for steel to crack in caustic solutions increases with temperature or concentration of the caustic.

In many stress-corrosion failures, the attack occurs along localized paths. For example, the metal may show no visible corrosion adjacent to the crack. These paths of localized attack may be areas of lower corrosion resistance than the surrounding portions of the metal; in these instances, the corrosion is electrochemical in nature with the attacked area anodic and the surrounding metal cathodic, thus setting up a corrosion cell similar to the cells described in galvanic or two-metal

By Mars G. Fontana
Professor of Metallurgical Engineering
Director, Corrosion Research Laboratory
Ohio State University

corrosion.* Once localized attack begins — in the form of a pit, crack or crevice — the effect is accelerated because these areas serve as stress-raisers.

Numerous types of stress-corrosion specimens for testing purposes have been devised. Perhaps the most common is bent like a horseshoe, and stressed by taking up on a through bolt at the ends. Simple beam specimens, cold worked specimens, and wedge shaped static cantilever specimens are also used. In connection with a particular problem concerning a shell and tube heat exchanger, the writer once used tubular specimens made by expanding short pieces of tubing in a split mandrel, thus simulating the rolling of tubes in a tube sheet. The holes were of several degrees of oversize to vary the amount of cold work. In this problem, the admiralty brass tubes had failed at or near the tube sheets because of an excess of rolling.

One of the most interesting cases of stress-corrosion of steel, in the writer's experience, involved stresses induced in the metal because of severe thermal gradients across the 2-in. wall of a large autoclave. These vessels contained a molten sodium-lead alloy, and they were heated or cooled by a fluid of large heat capacity known as "Dowtherm" circulating in the outer jacket. Decreasing the temperature of the Dowtherm during the cooling cycle from 200 to 100° C., in order to decrease the total time per batch and thus increase production, resulted in rapid failure of the autoclaves, and shut down the plant. This change in the coolant temperature increased the temperature drop across the wall from 110 to 154° C. Calculations showed that a temperature differential of the latter size induced a stress of 39,000 psi. in the metal. This high stress at the temperature of the operation readily accounted for the rapid cracking of the autoclave. The deepest cracks occurred adjacent to the welds, but deep cracks were also observed in the parent plate far removed from joints. Figure 16 shows one of the cracks in the parent metal; it started at the surface and is approximately 1 in. deep.

It is well known that the so-called aging steels are somewhat susceptible to stress-corrosion. Gradual precipitation of secondary phases within solid steel and other alloys often contributes to stress-corrosion failures. Mixed acids (sulphuric and nitric), nitrates and caustics are oftentimes the chief offenders as far as corrosive environments to steel are concerned. For example, large steel tanks erected in the field by welding developed very bad leaks and large cracks after only a few months of service when storing mixed acid.

Fig. 16 — Small Sample Cut From 2-In. Plate in an Autoclave, Showing Stress-Corrosion Crack Extending About Half Way Through. Natural size

A refrigeration condenser cooled by good quality inland river water failed by cracking, with the cracks starting inside the admiralty brass tubes. The cause of this failure was difficult to find, but it was finally attributed to a small amount of organic matter which deposited on the surface of the tubes. Since this condenser only operated during the warm months, it was idle several months each year. Apparently the organic matter decomposed during shutdown, with resultant formation of ammonia or amines which was destructive to the alloy from the stress-corrosion standpoint.

Copper itself is quite immune from stress-corrosion. Although generalizations are often undesirable, it can be stated that the addition of zinc to copper to form brasses increases the susceptibility to stress-corrosion and this tendency increases with the zinc content of the alloy.

The low-alloy aluminum materials, such as 2S (commercially pure metal) and 3S (1¼% Mn), most widely used in chemical equipment, give little difficulty from the stress-corrosion standpoint. The picture is quite different for the high-strength aluminum alloys; in fact, it could be stated that the biggest obstacle in the way of further increasing the strength of aluminum alloys is their susceptibility to stress-corrosion.

Stainless steels, which are widely used in chemical plants for corrosion resistance, generally do not fail because of stress-corrosion except for certain conditions — in particular, strong chloride solutions at high temperatures. Concentrated boiling $MgCl_2$ solutions are apparently most harmful. $BaCl_2$ has caused cracking in evaporator tubes. In one piece of equipment, cast 18-8 rolls, made by pressing trunnions into the ends of tubes, cracked in the stressed ends. These rolls were subjected to a dilute Na_2S solution made from a good grade of process water which had a normal (low) chloride content. This problem was solved

*See *Metal Progress* for March, p. 382.

by making a threaded joint between trunnions and tube.

Stress-corrosion failures of nickel and its alloys are uncommon in the chemical plant. The few cases that have been encountered involved strong caustic at high temperatures.

Perhaps the most common method used for combating stress-corrosion consists of prior stress-relieving heat treatments. Internal or residual stresses in the metal or equipment can be greatly minimized by heating at a moderate temperature. For example, it is common practice to stress-relieve welded steel equipment by annealing in the range of 1100 to 1200° F. The failures of nickel tubes in caustic service could be prevented by stress-relief anneals in the temperature range of 1000 to 1600° F.

Of course, another effective preventive involves the proper selection of alloys. 18-8SMo, for example, is superior to 18-8S for resistance to stress-corrosion. A red brass (15% Zn or less) should be more resistant than a cartridge brass (30% Zn). The selection of materials should balance the probability of stress-corrosion failure and cost of the material. In other words, the economics of the installation must be considered.

A protective metallic or nonmetallic coating is often beneficial. For example, the high-strength aluminum alloys are often clad with relatively pure aluminum for better resistance to stress-corrosion. Organic paints, separating corrosion medium from metal or alloy, are often used.

Design of the equipment is also important. Sharp corners or fillets, which would act as stress-raisers, and high applied stresses should be avoided. Corrosion inhibitors are sometimes beneficial. In general, the use of more corrosion resistant materials and changes which decrease the corrosiveness of the environment are helpful.

Combating Corrosion

It may be desirable to list briefly here the eight general methods used for combating corrosion. These methods should be considered in the solution of any corrosion problem:

1. Alloying or selection of a more corrosion resistant material.
2. Metallic, inorganic or organic coatings.
3. Removal of the corrosive agent (such as deaeration of water).
4. Inhibitors.
5. Cathodic protection.
6. Use of nonmetallics (e.g., glass or rubber).
7. Purification of the metal.
8. Improvement of equipment's design.

Methods 1 through 6 are used in many applications, and they are all commercially feasible. Method 7 is the least frequently used, and only in special cases. The method used depends on the nature of the problem involved. Cost is, of course, very important, and in practically all cases the economics of the problem more or less dictates the method used when two or more alternatives are applicable. Sometimes the mechanical properties of the material of construction are an important factor. Method 8 is usually possible.

Improving the Design

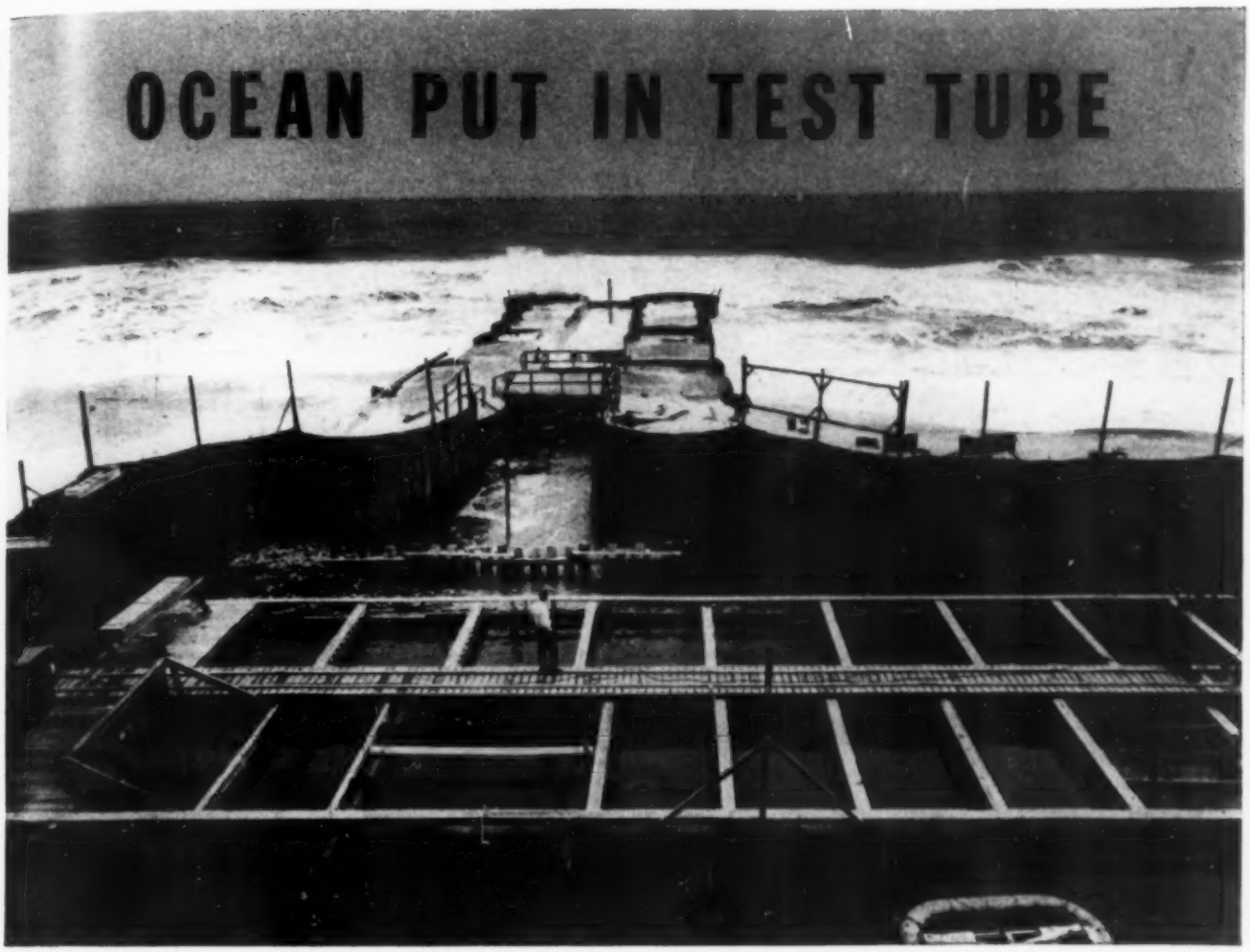
It is generally well known that *mechanical* failures are primarily due to improper design, and seldom to defective material. However, a failure from corrosion (in a chemical plant, for example) is almost universally ascribed, by the plant man, to "defective material — improperly heat treated". In most instances this is not the correct answer.

Variations in corrosion rates are usually allowed for by providing metal thickness twice that which theoretically would give the desired life. Often an increase in thickness, without changing the material, will save a lot of money in the long run. (Automobile drivers in northern latitudes where salt is used on icy streets know that this would be true of fenders!) For example, when the tubes in heat exchangers in a contact sulphuric acid plant were changed from 13-gage to 10-gage walls, it saved several thousand dollars annually. Often it is cheaper to provide plenty of cast iron than theoretical amounts of a more noble alloy.

Design of tanks and pressure vessels should avoid chance of stagnant areas. Welded joints with generous radii and smooth surfaces are preferred over riveted construction, to avoid crevices and concentration cells. The lining should be carried out over the rounded top rim and form a gutter leading overflow and splash to a downspout. Bottom outlets should provide for *complete* drainage. Heating coils should not touch bottom or sides, else hot spots will speed-up the corrosion. Foundations and supports should prevent accumulation of moisture and spills.

Turbulence is often the cause of excessive corrosion at inlets or at changes in cross section — life of the metal at such places can easily be doubled by "stream-lining" the passages.

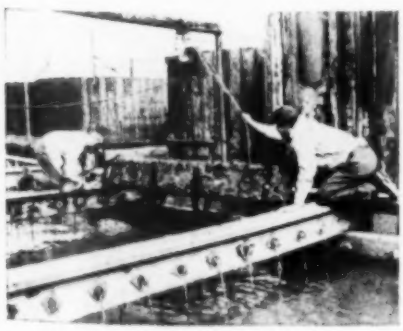
Standardization of design, to permit interchange of equipment or facilitate repair from stock parts, is quite desirable. One extreme instance is where pump casings and impellers are standardized *in shape* but made and carried in stock of various corrosion resistant alloys. If one combination fails in a certain location, another combination can replace it in a very short time.



Tides and Waves Harnessed for Corrosion Data to Provide Better Materials for Industry...

INCO goes down to the sea...to get the ocean's own verdict on metals and alloys.

Here, at Kure Beach, the Atlantic has been made a giant test tube for studying the corrosive attack of salt water and salt air.



Raising a specimen rack at the site. Specimens are given detailed examination in the control laboratory.

Many different tests are made on thousands of metal specimens. Each is carried out under natural conditions expected in service.

The picture above shows the testing basin where metal panels are immersed in the ocean's own brine. This type of test shows how well the metal resists corrosion, and also whether it retards the growth of barnacles and other marine life.

In other tests, metals are exposed on racks to salt air and salt spray, or whirled through the water at high velocity.

These and other tests often take months...sometimes years. But the object remains the same: *To discover which metal or alloy is best suited to a specific task.*

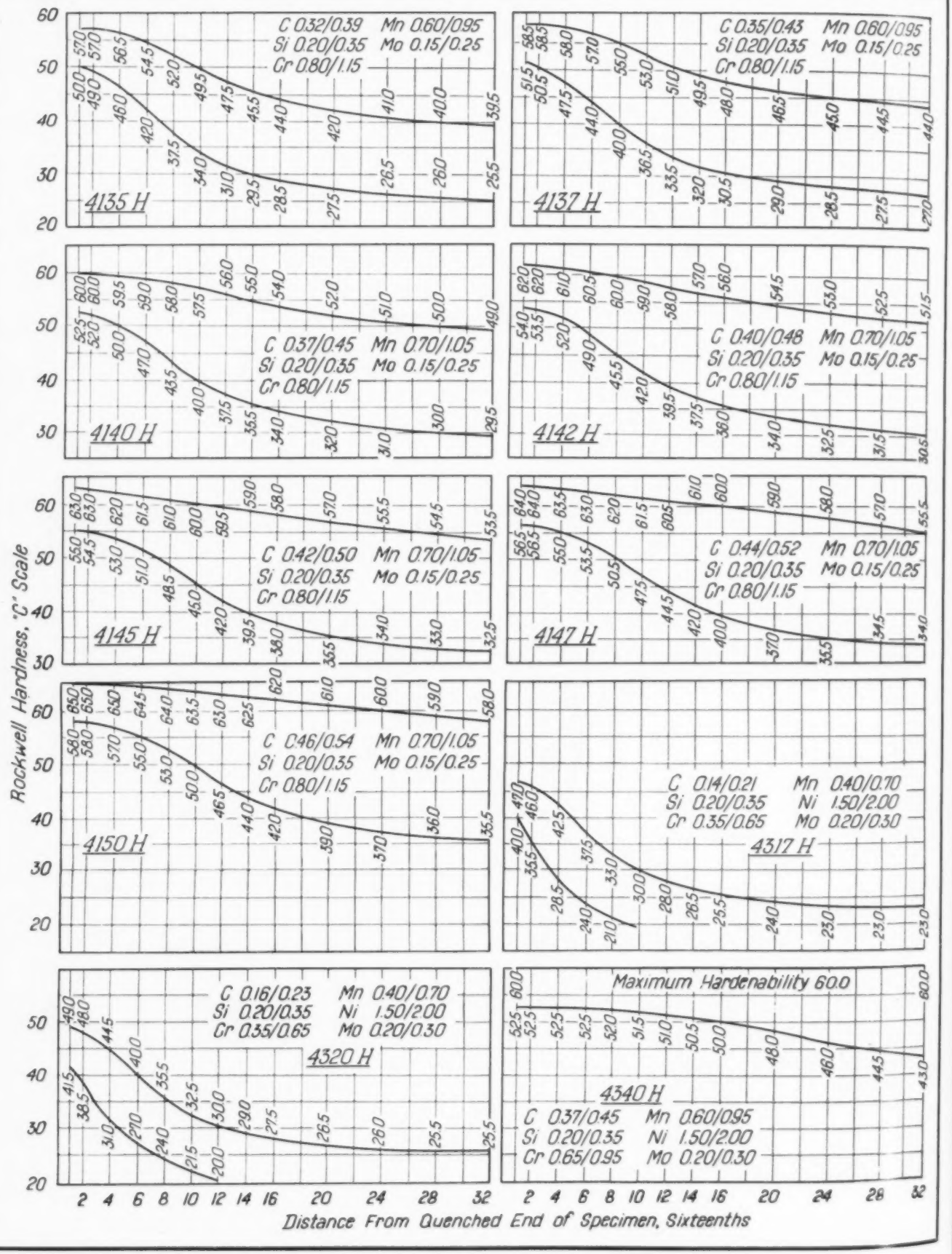
Just one of the many ways International Nickel helps you and other manufacturers make exactly the right choice of materials to perform better, longer.

* * *

Over the years, International Nickel has accumulated a fund of useful information on the properties, treatment, fabrication and performance of engineering alloy steels, stainless steels, cast irons, brasses, bronzes, nickel silver, cupro-nickel and other alloys containing nickel. This information is yours for the asking. Write for "List A" of available publications.

EMBLEM OF INCO SERVICE

Tentative Hardenability Bands, 4135H to 4340H



This account is adapted from a study submitted to the James F. Lincoln Arc Welding Foundation in competition in its recent "Design For Progress Award Program". The manufacturing methods are also adaptable for gas turbine blades, welded of stainless sheet.

Hollow Blades

for Axial Flow Compressor

THE Northrop-Hendy Co. is engaged in research and development of gas turbines both for aircraft and stationary power plants, having devoted its entire efforts for the past seven years toward achieving the ultimate in high power per unit weight and high efficiency in this new type of prime mover.

Backed by a firm conviction that the gas turbine will supplant displacement engines for all units above 750 hp. in aircraft, the greatest attention has been devoted to this field. Here, while specific weight (pounds per horsepower) is important, specific fuel consumption becomes far more important if long-range aircraft are considered, because an engine will burn several times its own weight of fuel during a single flight, and good fuel economy is reflected in useful load capacity.

As is well known, the gas-air combustion mixture must be supplied to the turbine burners at considerable pressure, and the efficiency of the air-compressing element has very important influence on the fuel economy of the complete power turbine unit. At the present time two types of compressors are used. These are the centrifugal flow compressor and the axial flow compressor. In the centrifugal flow compressor, air at normal pressure is drawn in at the axis of the rotating unit and forced out radially by suitable blades, and acquires velocity and pressure by centrifugal forces. The axial flow compressor is similar to a multistage steam turbine acting in reverse, where the speed and pressure of the air are increased as it passes along through a series of vanes set on the rim of rotating disks, alternating with equally spaced vanes fixed into the outer casing of the compressor unit. Though more involved mechanically, the axial flow compressor is inherently much more efficient as a pressure increaser and air pump than the centrifugal type — particularly for the higher pressure ratios required when the gas turbine is used to drive a conventional propeller. Much effort is therefore being expended to perfect it, both from an aerodynamic and fabrication standpoint.

As indicated above, axial flow compressors consist of several stages, each comprised of one rotating and one stationary set of airfoil blading. Each set might number from 30 to 50 blades. A typical compressor for a gas turbine for delivering power from the driven shaft will consist of from 10 to 16 such stages and could contain up to a total of 1600 blades, both rotating and stationary.

This blading, in the interest of optimum over-all aerodynamic efficiency, must conform to exacting requirements relative to cross-sectional profile and rate of profile change along its length. This results in elements which can be readily fabricated by no existing standard machine tools, nor is it possible to produce them by any straightforward geometrical cutting motions. This can

By Russell Meredith and A. J. Phelan
Welding Engineer Chief Engineer
Northrop-Hendy Co.
Hawthorne, Calif.

more clearly be understood when it is realized that no two sections cut through the blade along its length will have the same profile, and that the blade is twisted from one end to the other to conform to varying circumferential velocities at different distances from the center of the shaft.

It might be well to pause for recapitulation at this point. First, there is every indication that

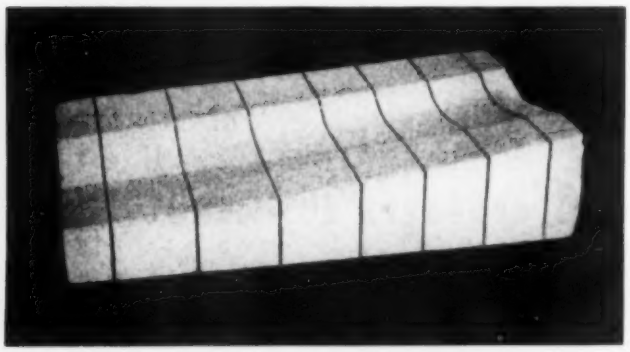


Fig. 1 — Templet Bank Filled With Plaster Ready to Be Inserted in Plaster Pattern for Drop Hammer Die

the gas turbine is here to stay and replace many existing prime movers. Second, the gas turbine requires an air compressor and this air compressor absorbs a notable percentage of the power generated by the turbine. Third, the axial flow compressor must be used for its efficiency. Fourth, this compressor requires a great number of blades. Last — but of great importance — these blades are difficult and time-consuming to produce.

The need for a low-cost production method is clearly indicated.

At the present time practically all blading in gas turbines is made by one of three methods — all time-consuming and, consequently, costly. First, there is the method of profile machining from a master; this is very slow and costly. Second, there is the forging technique which leads to considerable variation in weight, blade to blade, resulting from required dimensional tolerances. Third, there is the precision or "lost-wax" casting technique — also costly.

Confronted with the foregoing problems in all their ramifications, we concluded that hollow blades fabricated of sheet metal parts formed in steel dies and arc welded into a complete whole would answer the requirements of precision, light weight, and mass production potentialities. The sheet metal blade is very light and, while weight is saved in the blade itself, the real saving is in the rotor, whose weight varies exponentially with the weight reduction of the blade. Hundreds of pounds of rotor weight can therefore be saved by the use of such blades and in aircraft this is, of course, invaluable from a standpoint of useful load.

Convinced that after a reasonable development program a truly low-cost precision blade could be produced on a mass-production basis, work was launched on a research project. While turbine rotor and stator blades have also been fabricated experimentally from stainless sheet, only compressor blades will be dealt with herein.

Compressor rotor blades, because of high centrifugal and vibratory stresses at temperatures up to at least 600° F., must of necessity be constructed with excellent physical qualities as well as to close dimensional tolerances. We do not intend to show merely that a product can be

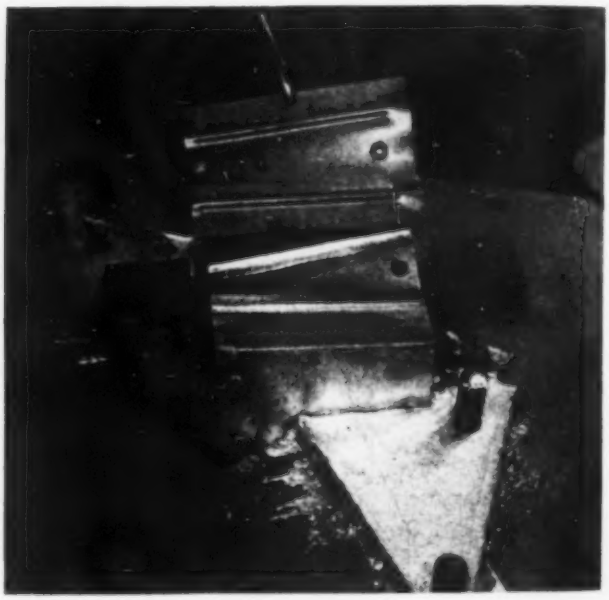


Fig. 2 — Zinc Alloy Lower Die, Fixed to Bed of Drop Hammer by Lead Slabs. Hot formed part is being removed by workman

manufactured cheaper by arc welding than by other methods, but emphasis is also placed on its physical advantages over cast or forged construction. Moreover, it is hoped that experimental projects such as described will help lead the way to the welding of many other precision articles heretofore considered impossible, and to dispel any ideas which might exist in the minds of design engineers that arc welding is just a rough-and-ready means of putting things together. However, in order to do precision welding, a *determination* to do a good job is imperative; also, such items as good tooling, jigs, welding procedure, and selection of welding equipment are of paramount importance.

Material

First to be considered was the sheet metal for the job. A straight high-chromium stainless steel (A.I.S.I. Type 410, 12% Cr, 0.15% C) was selected because it provides certain desirable blade qualities such as high strength when heat treated, plus fair corrosion and heat resisting properties.

Rolls of strip, 300 to 400 ft. long, 9 in. wide, 0.025 and 0.031 in. thick, were purchased from the mills. From these rolls were cut various sized drop hammer blanks. The actual blades have chord dimensions varying from 1⅜ to 2¼ in. and lengths from 2 to 6 in. However, drop hammer blanks had to be cut considerably larger for forming and welding allowance.

Since time was of the essence and because of the simplicity of die construction, the gravity drop hammer (rope release) was chosen. Drop hammer dies were made by casting high zinc alloy ("Kirksite", trade named) in sand molds. It is a material that is capable of withstanding heavy blows without breaking; the dies are easily made, have high salvage value, and the material is well known to workmen in the aircraft industry.

Manufacture

The first step is the preparation of the lower die for either leading or trailing surface of the blades for one particular stage. Vellum drawings, ten times actual size, were made of several airfoil sections along the blade's length. Using these drawings, master sheet-metal templets were made from which actual size templets were reproduced photographically to actual size on glass plates, and transferred to templet stock by etching. These actual size templets were then sawed and filed precisely to the etched lines, and bolted together to form actual blade-size templet banks. Each section was held in its proper location by the use of spacers, and the spaces between sections filled with plaster of paris and surfaces carefully smoothed. Figure 1 shows a templet bank at this stage.

Such a templet was then set in the center of a larger plaster pattern of about the same area as the sheet metal blanks. The top surface contained end dimples for location points and ridges along the edges for grippers. Zinc alloy dies, both upper and lower, were cast in sand molds from these plaster patterns. Figure 2 shows the lower die mounted on the drop hammer bed; the triangular shaped pieces are lead, poured around steel pins and against the die.

At first, blade valves were formed at room temperature. While the forming and contours were acceptable, it was discovered that subsequent heat treatment of the finished (welded) blade caused some distortion. To prevent this it was decided to try hot forming, and the blanks were thereafter heated in a small muffle furnace to 1200 to 1400° F., with anticipated good results. Figure 2 also shows a hot formed part after the first blow with the bare punch. Indexing dimples may also be seen, which were used to drill parts for subsequent indexing purposes. After the formed part had cooled it was restruck (with a ¾-in. rubber pad between it and the upper die or punch) to remove any warpage that may have occurred during cooling.

Surplus metal must next be removed from the sides of these stampings. To mark them for rough trimming, a master trim templet was placed on the stamping, properly located by means of indexing dimples, clamped down, and the correct outline scribed with a scratch awl or scriber. (The dimples in the parts are of no further use beyond locating the stampings in the fixture for drilling of indexing holes.) Extra metal is trimmed off by a band saw — a hand operation.

Final trimming and beveling is done as shown in Fig. 3, using a hand-feed milling machine and a special fixture and milling cutter. The fixture

Fig. 3 — Hand-Feed Milling Machine With Fixture Holding Blade Stamping for Edge Trimming

consisted of a top and bottom "Kirksite" casting molded to fit the blade contour. Blade halves were clamped in this set by means of a tee-handled bolt; the entire fixture rotated about centers on either end. A step was ground in a spiral fluted milling cutter in order to trim the chord-wise dimension (plus a predetermined burn-down allowance for welding) and at the same time bevel the edges. Manufacturing sequence is shown in the mechanical drawing, Fig. 4. Step 1 shows the end shapes of the two surfaces as formed and rough trimmed, while Step 2 shows the assembly after faying surfaces have been milled and edges cut back to welding allowances — both operations done simultaneously in the equipment shown in Fig. 3. Blade halves are now ready for welding.

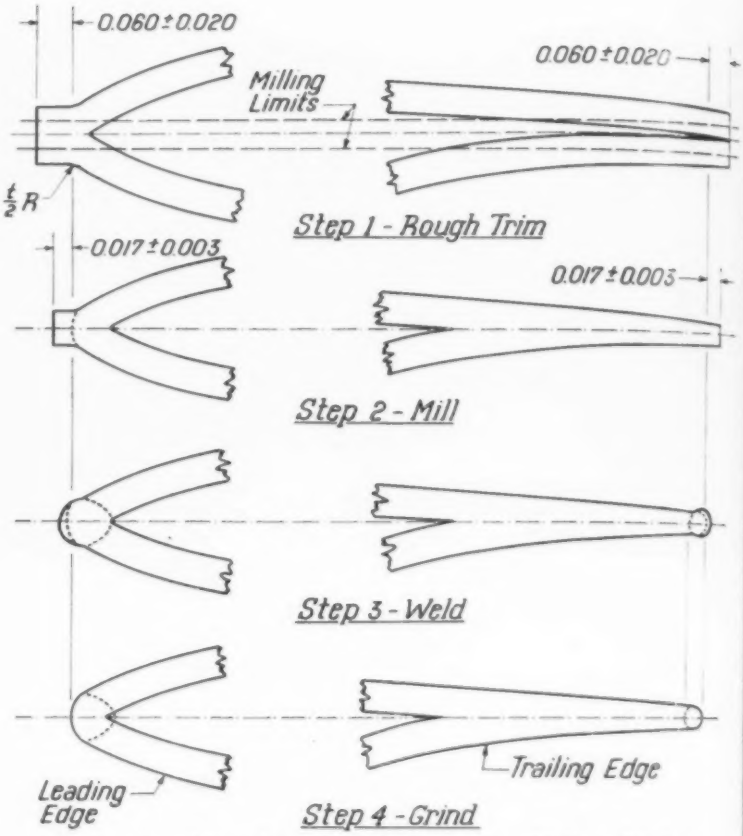


Fig. 4 — Manufacturing Sequence for Hollow Blades

Welding Process

After experimenting with several other processes of welding, and also with various brazing methods, the "Heliare" process proved to be superior. This is arc welding in a controlled atmosphere with a specially constructed torch in which a tubular tip is used to carry an inert gas to the work and surround a refractory electrode which carries the arc to the work. The most commonly used electrodes are carbon and tungsten. The gases are helium and argon. In our work carbon was used for the electrode and helium for the gas; the current was straight polarity, furnished by a 150-amp. d.c. Lincoln welder.

Figure 5 shows the operator and equipment. No filler rod was used on the leading and trailing edge welds, as may be seen. The blade edges were merely fused together which, with our method of jigging, was easily accomplished and very neat, uniform welds were obtained. The welding jig is in two closely fitting pairs, and is provided with various means of maintaining blade alignment, such as indexing dowel pins for locating the blade halves, thumb screw clamps (spring loaded) for holding the parts down, dowel pins for aligning jig and blade halves with respect to each other, and set screws for controlling the maximum thickness of the blade. Sheet copper strips pinned to the dies on both sides of the weld joint served to prevent the fixture from overheating; they also aided in maintaining a uniform weld bead.

After welding, the welds on the leading edge were checked visually for penetration by looking through the

Fig. 5 — Welding Jig Containing Blade Halves, Clamped in Vise. Operator merely melts down protruding edges to limits shown in Fig. 4

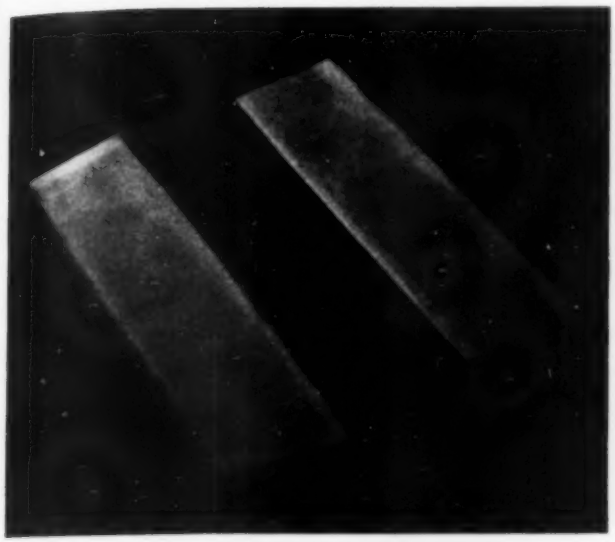


Fig. 6 — Welded Blade at Left; Blade With Edges Smoothed (Finished) at Right

Fig. 7 — Above: Anchor, With Milled Island Fitting the Contour of the Blade; Below: Blade Welded to Anchor

blade. Surplus metal shown in Step 3 of Fig. 4 was removed on abrasive belts. Two grades of abrasive were used, 80-grit for roughing and 120-grit for finishing. Templets were used to obtain proper contours at the leading edge.

At this point the blade was trimmed to proper length and taper. It was clamped in a cut-off fixture with provisions made for indexing, and mounted on a base plate at the proper angles for cutting off with the side of a fluted milling cutter.

Blade ends were marked with the use of a trim templet, and the anchor-end rough trimmed prior to milling. The tip, or outer end, was rough trimmed after the anchor-end milling operation and prior to the next operation of welding the blade to the anchor. (Final tip trimming was done by grinding on a lathe after the blades had been mounted on rotor disks.)

Now the blade has to be welded to its anchor (Fig. 7). A stub $\frac{3}{32}$ in. high with an inner island $\frac{1}{32}$ in. high and shaped to the inside contour of the blade was milled on a dovetail type of anchor. The outer island was milled 0.020 in. larger than the outside contour of the blade to provide extra filler metal, plus insurance against undercutting when the anchor weld is ground smooth.

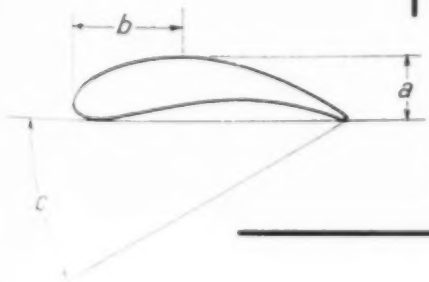
Blade and anchor are assembled by hand and placed in a simple jig, providing means of locating and holding blades to the proper angles with respect to the anchor. Clearance was provided for expansion during welding. Blade and anchor were tack welded in several places and "Heliarc" welded, using bare filler rod 0.046 in. diameter of

Instructions for Inspection

Sample blades must be approved before full sets are manufactured. Uniformity of blades in any one set is of prime importance, and will be considered above any dimensional discrepancy when accepting or rejecting blades.

Visual — Sectional and longitudinal contours must be smooth, well faired, and correspond to design shape. No blade with pointed, blunt or irregular leading edge is acceptable.

Dimensional — Twist angles of each section are to be measured on six blades for each set or stage. One blade from each stage is to be cut at the section lines, and these sections photographically enlarged 10 diameters for comparison with 10 × master templets. This may also be done with a comparator.



Dimension	Tolerance From Design	Tolerance From Blade to Blade
Chord length	±1%	±0.25%
Maximum thickness, *a*	±0.5%	±0.25% of chord
Location of maximum thickness, *b*	±2.5% of chord	±1% of chord
Trailing edge thickness	±0.003 in.	±0.003 in.
Blade twist angle, *c*	±30 min.	±30 min.

Type 410 steel. Weld penetration was inspected internally by a flashlight with a long lucite rod attached. Excess weld metal was removed with an abrasive belt.

Inspection

Due to the stringent service of these blades, rigid rules of inspection were necessary in order to obtain the highest quality product.

After blades were welded to anchors and ground, all welds were X-rayed. Since the trailing edge weld could not be visually inspected for penetration, X-ray methods were worked out by which this could be done. Insufficient penetration of welds, blowholes, or cracks were reasons for rejection.

After passing this inspection, blades were normalized in a controlled atmosphere furnace. Racks were provided for suspending blades by the anchor end during heat treatment, so as to prevent any undue deflection of the hot blades.

Blades were next hydro-blasted to remove any heat treatment scale; this also aided visual surface inspection.

Fig. 8 — Box Gage for Blade Contours and Angles

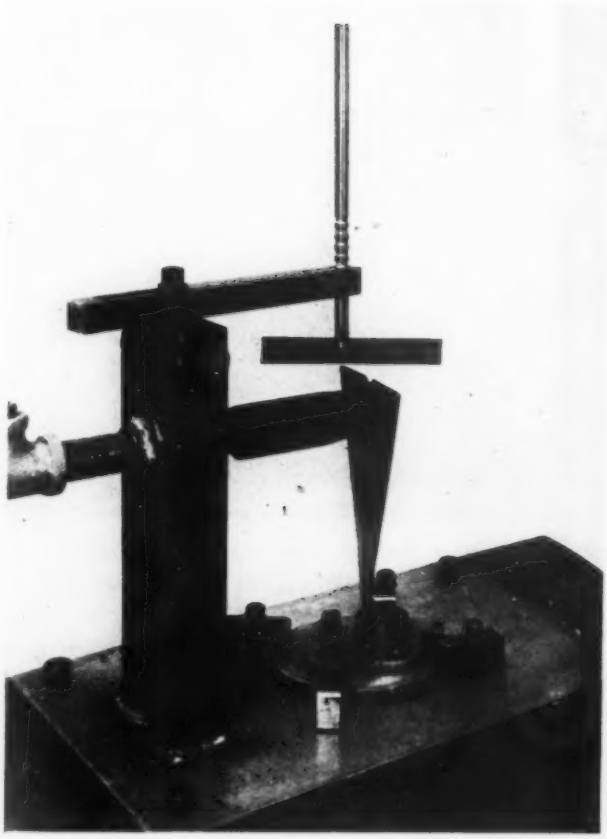


Fig. 9 — Setup for Fatigue Test. Vibration imposed by air blast near upper end

All blades were proof loaded prior to mounting on compressor rotor disks. This was done by clamping two blades at opposite ends of a spin arm and spinning at slightly higher rotations per minute than would be encountered in operation. No arc welded blades were lost in such spinning.

After blade assemblies had been spun a dimensional inspection was carried out in accordance with specifications shown in the box on p. 845. This was a tough bill to fill for a welded product. However, more than 1500 blade assemblies were fabricated and passed. Figure 8 shows a box gage used to check contours and angles.

Testing

Numerous blades were pulled to destruction in a tensile testing machine. While these arc welded blades had high load-carrying ability with a considerable safety factor from a design standpoint, this alone was not sufficient assurance of a serviceable blade because this did not give any information about the fatigue life of the blade.

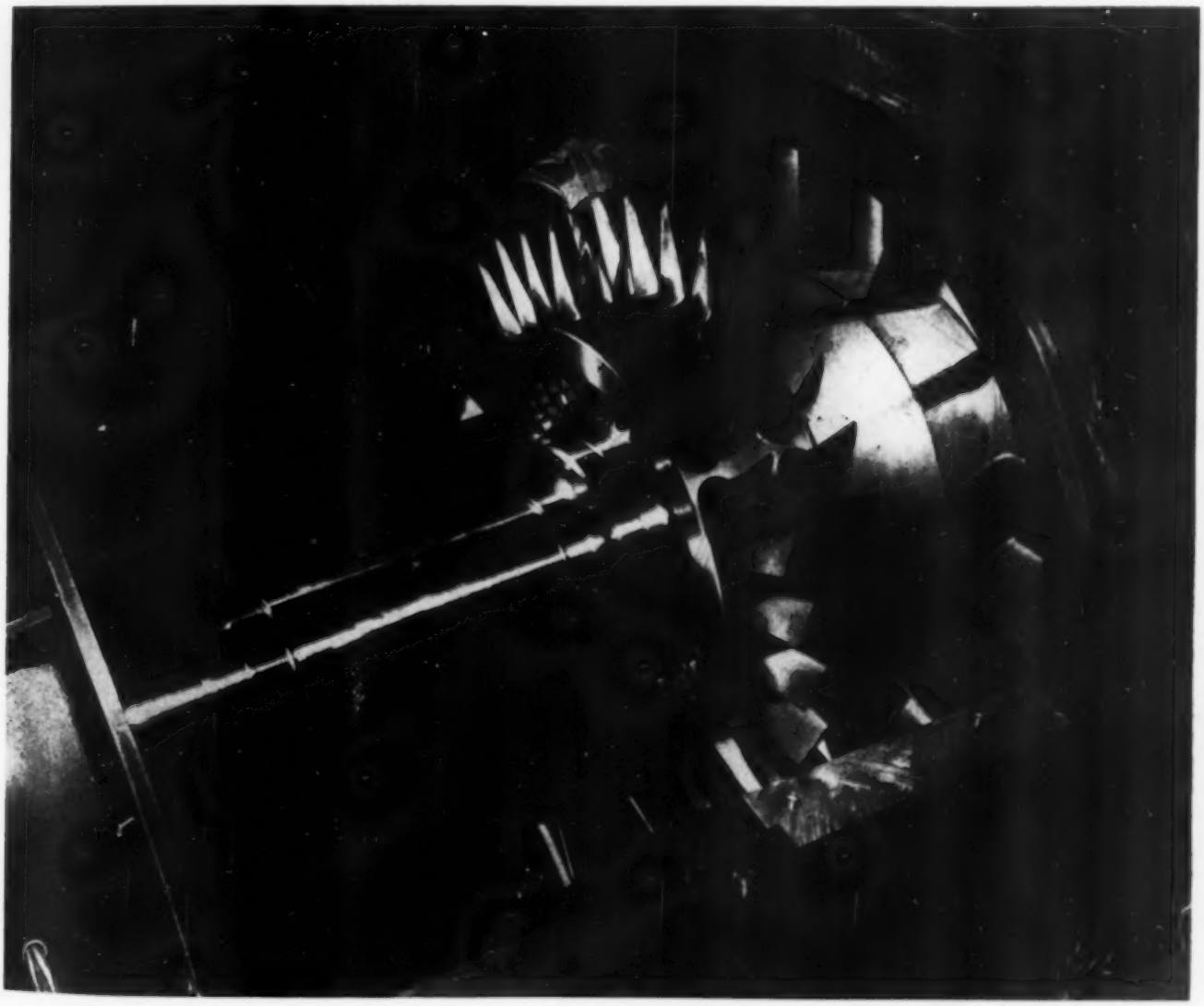
Figure 9 shows a device for vibrating blades in order to obtain fatigue data. Stresses were

imposed by an air blast impinging on one side near the tip of the blade, causing it to vibrate a measured amount and throwing a computed stress on the root section of the blade. The magnitude of root stress was controlled by the amplitude of vibration at the tip, established by the amount of air flow, which in turn was controlled by a valve in the air line.

In these tests it was found that arc welded sheet metal blades which passed all inspections had approximately twice the fatigue life at equivalent root stresses of the forged aluminum alloy blades which had previously proven satisfactory for actual use in axial flow compressors. No forged steel blades were available for comparative vibration tests, although it is the opinion of competent engineers that they would, in all probability, have a somewhat greater fatigue life. On the other hand, the rigid yet light construction of the sheet metal blades yields a part that vibrates at very high frequencies, conceivably far above the frequency of most of the exciting forces likely to be encountered.

A large amount of compressor testing has been conducted in such assemblies as shown in Fig. 10, using the arc welded sheet metal blades, with satisfactory results. A new product such as this is never really out of the evolution stage until thoroughly proven by a year or two of intensive service in the field. This item is no exception to the rule. Some modifications are indicated by service to date. However, there is still every reason to feel that the arc welded sheet metal construction will satisfy an urgent demand for a low-cost, light-weight compressor blade of high precision.

Fig. 10 — Two-Stage Compressor (Top Casing Removed) Bladed With Hollow Blades Used to Test Performance



Correspondence

X-Ray Diffraction Standards

WASHINGTON, D. C.

To the Readers of METAL PROGRESS:

Through a cooperative program sponsored by the American Society for X-Ray and Electron Diffraction and the American Society for Testing Materials, the National Bureau of Standards is preparing a card index of X-ray diffraction patterns of chemical compounds. The first substantial contribution to this diffraction data (for about 1000 substances) was made by Dow Chemical Co. Data on almost 2000 others — mostly from other industrial laboratories — have been collected and scrutinized. The diffraction data are presented in terms of interplanar spacings and relative intensities of the lines.

In comparisons and verifications at the Bureau of Standards, use is made of an improved Geiger counter technique, which not only measures the atomic spacings more accurately, but greatly extends the range of diffraction angles and thus can determine small changes in unit cell size which occur in solid solution series. The practice has been adopted of analyzing two specimens of each substance — one showing a completely random orientation of small crystals, and the other smoothly packed to present an effective flat surface.

Since the care necessary in choosing high-purity compounds is not as great as for spectrographic analysis, samples should be chosen first for absolute identity and secondly for freedom from impurities. Anyone who may have such samples that may serve as a basis for such diffraction data is invited to send small amounts to the undersigned for this purpose. Obviously, the usefulness of X-rays for analyses of unknown compounds and mixtures thereof increases with the size and effectiveness of the expanding index.

H. E. SWANSON
In Charge of Project
National Bureau of Standards

Advantages of Shot-Peening

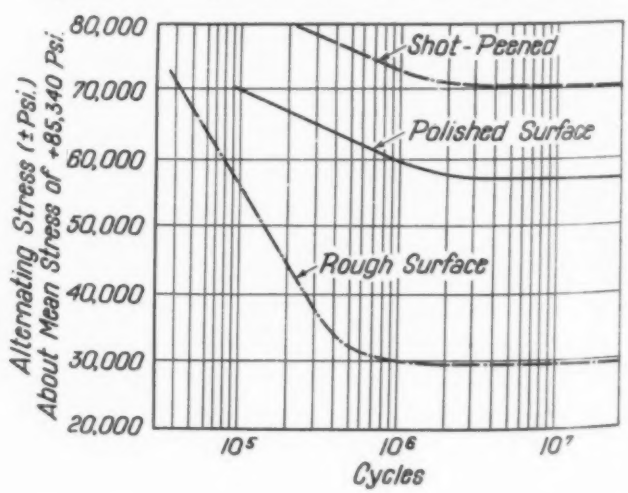
TURIN, ITALY

To the Readers of METAL PROGRESS:

Much information has already been published on the advantages of shot-peening, but specific and new results are always interesting and will be of help in developing the technical aspects of this subject. Hence, we submit the results of two series of tests on spring materials:

In the first, S.A.E. 9260 silico-manganese spring steel (in the form of the flat bars used for leaf springs) was loaded so as to have an extreme fiber stress in bending of 85,340 psi. The load was then varied cyclically about the original value, and the endurance limit determined — in this case as a plus-and-minus value about the original stress. Leaves with three surface qualities were tested: *(a)* rough, hot rolled as received from the steel mill, *(b)* smooth polished, and *(c)* original surface shot-peened. All these flat bars were heat treated identically before testing by heating to 1580° F., quenching in oil, and tempering to Rockwell C-46 to 48.

Fig. 1 — S-N Diagram for S.A.E. 9260 Leaf Springs as Surface Condition Varies (Bend Tests)



Results of the tests follow:

Surface	Endurance Limit	Gain
Rough	85,340 ± 28,450	
Polished	85,340 ± 56,590	100%
Shot-peened	85,340 ± 71,120	150%

S-N curves for these tests on leaf springs are shown in Fig. 1. The figures in the column above marked "gain" represent improvement in endurance limit and not improvement to life of specimens under a given range of stress. As is apparent from the shape of the S-N curves, the relative life is much more greatly increased by shot-peening if the springs are loaded to stress ranges *greater* than the endurance limit; however, the figures given in the table are usable to designers who wish to insure trouble-free operation for an indefinite life. The same remarks apply to the tests on torsion springs, about to be described.

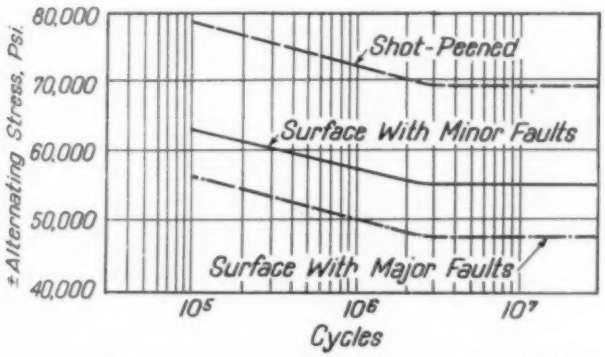


Fig. 2 — S-N Diagram for Oil Tempered Helical Springs as Surface Condition Varies (Torsional Stress)

The second program of testing related to helical coiled springs tested in torsion. Composition of steel corresponded to S.A.E. 1070; it was received as 0.138-in. rounds, and the springs were oil tempered after coiling in the steel plant.

Coils with three different surface conditions were tested: *(a)* Oil tempered spring wire as received, surface faulty, blued after coiling; *(b)* oil tempered spring wire as received, commercially acceptable surface, blued after coiling; *(c)* steels *(a)* and *(b)*, shot-peened. Endurance limits shown below were obtained for all three surface conditions and for symmetrical loading (that is, equal plus and minus torsional stress) and for unsymmetrical loading (from zero up):

Surface	Symmetrical Loading*	Zero to Maximum*
Faulty	±47,500 psi.	0 to 80,146 psi.
Commercial	±55,610	0 to 94,868
Shot-peened	±68,700	0 to 119,470

*All stresses calculated by the Wahl formula; K assumed to be 1.18.

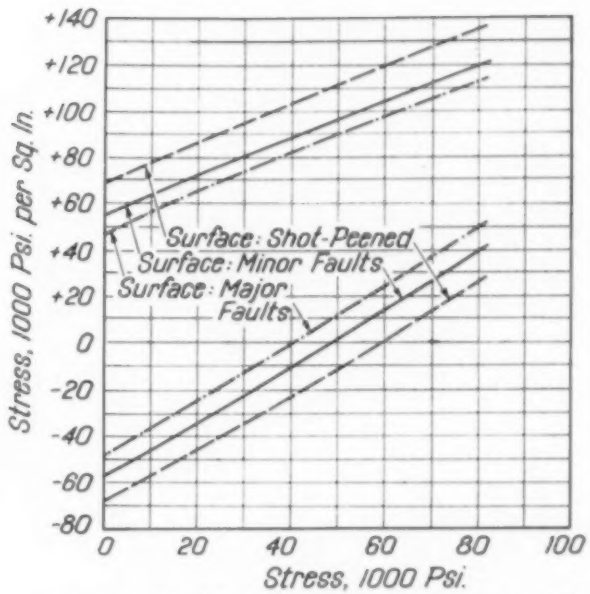


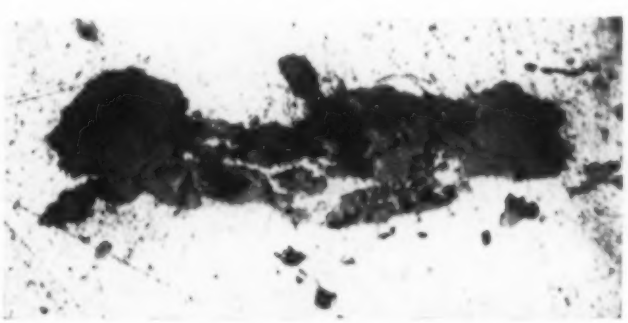
Fig. 3 — Modified Goodman Diagram for Oil Tempered Helical Springs (Wire 0.138 In. Dia.) Showing Influence of Surface Condition

Again, Fig. 2 shows the S-N curves for symmetrical loading. Gain in endurance limit by shot-peening equals 25% of the value for wire with commercial finish.

A modified Goodman diagram is given in Fig. 3 for this oil tempered spring wire for alternating torsional stresses. This shows the approximate safe range of stress when the average is any chosen stress up to +90,000 psi. Surface conditions are as described above for Fig. 2. In all our tests the standard intensity of shot-peening was 0.014 A-2, as measured with No. 2 Almen gage. Shot conformed to S.A.E. No. P19.

Alberto Oreffice
Luigi Locati
Chief Engineers of Steel Dept. and of Research Dept., respectively, The Fiat Co.

Cuproxylion



Lens-Trapped by Roland Mitsche When Hunting in Open Field of Inclusions in Copper Wire

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Personals

Omar V. Greene has been promoted by Carpenter Steel Co. from assistant general sales manager to manager of product development. **H. Sturgis Potter** was promoted from manager of toolsteel sales to sales manager in charge of all Reading products. Both have been associated with the company for several years.

John R. Graf has joined his father in the John C. Graf Co., Philadelphia, designers and builders of hydraulic presses and auxiliaries.

Stanley A. Richardson has been elected president of Midwest Steel, Inc., processors and dealers in stainless steel in Cleveland. He is also president of S. A. Richardson and Associates of Cleveland.

Gustave A. Weber is now connected with the M. W. Kellogg Co., Loom Div., Jersey City, N. J., as development engineer.

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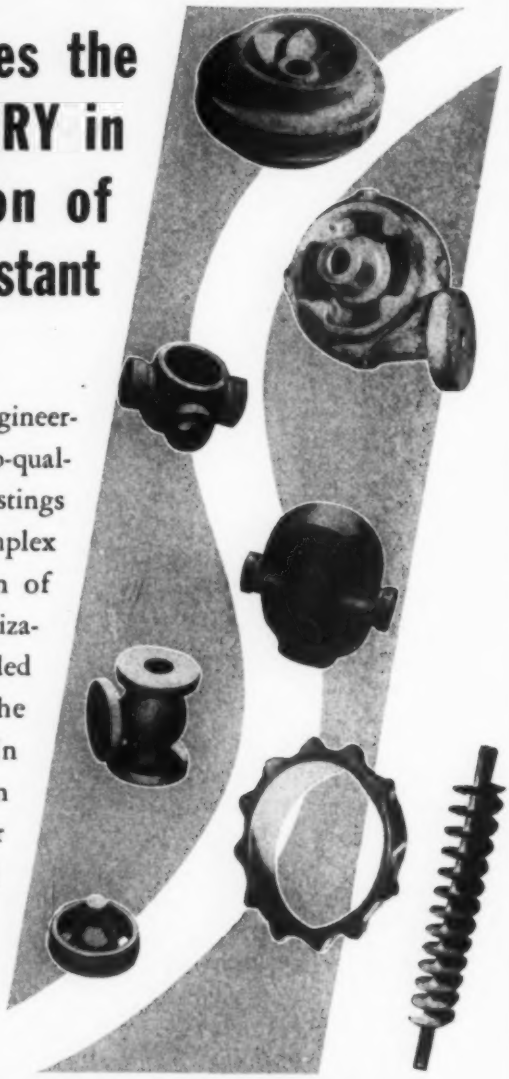
NEW BULLETIN containing useful technical data is available upon your request.



Stainless FOUNDRY & ENGINEERING CO.

5130 N. Thirty-Fifth Street • Milwaukee 9, Wisconsin

W. E. Falberg, for the past three years head of special steel sales at the Cleveland, Ohio, steel service plant of Joseph T. Ryerson & Son, Inc., has been appointed manager of alloy and stainless sales at the company's plant in Chicago, Ill.

Daniel J. Martin has been elected a vice-president of the Hughes Tool Co., Houston, Tex. Dr. Martin will be in charge of the research and engineering activities of the company.

Reynolds Metals Co. announces the appointment of **Neil F. Ritchey**, formerly metallurgical engineer in charge of nonferrous metallurgy in the laboratory of the Fort Wayne, Ind., plant of General Electric Co., as an engineer in the technical service department.

Ralph W. Rogers, Jr., has been transferred by the Aluminum Co. of America to its Davenport, Iowa, rolling mill where his position will be staff metallurgist. He formerly had the same position at the Alcoa, Tenn., rolling mill.

After graduation from Missouri School of Mines in January 1948, **George G. Kalbfkisch** accepted a position as metallurgical investigator with the Bethlehem Steel Corp., Bethlehem, Pa.

Formerly with American Bosch Corp. as buyer of raw materials, **Henry Gareau** is now with the sales department of Baldwin Duckworth Div. of Chain Belt, Springfield, Mass.

Frank B. Hays has been appointed manager of western states territory for Carner Pump Co., Muscatine, Iowa, covering 11 western states, Alaska, Hawaii, western provinces of Canada and part of Mexico.

Milo G. Spaich is now general manager of the American Forge Co. and vice-president and sales manager of Pacific States Steel Corp.

Wm. L. Rudin is engaged in nonferrous foundry consulting in Chicago, under the association name of Wm. L. Rudin & Associates.

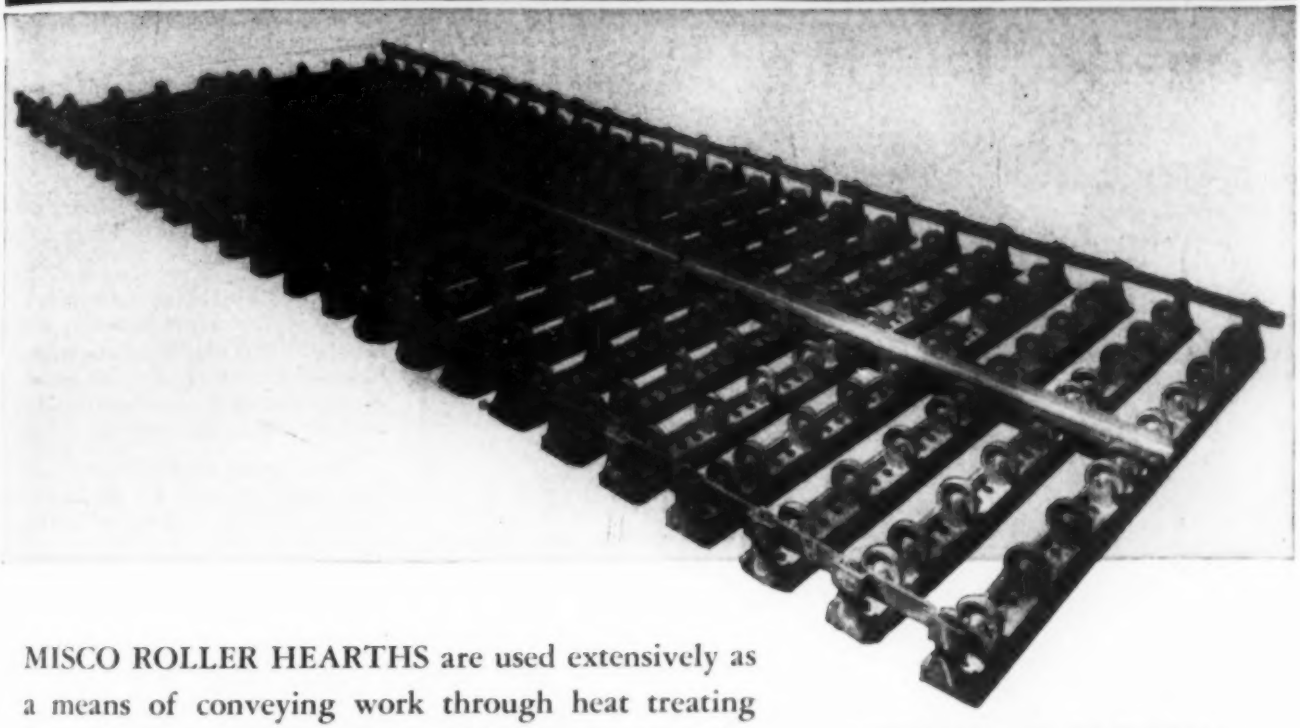
Milton C. Deiley is now employed by the Jones & Laughlin Steel Corp., East Pittsburgh, Pa.

William F. Emmons has recently been appointed metallurgical engineer at the General Electric Co., Philadelphia.

Following graduation, **Emmett H. Mann** has been appointed metallurgical engineer of the compounds division of the General Electric Co., Pittsfield, Mass.

MISCO HEAT RESISTING ALLOY ROLLER HEARTHS

LIGHT • DURABLE • STRONG



MISCO ROLLER HEARTHS are used extensively as a means of conveying work through heat treating furnaces. They are designed to distribute substantial loads over smoothly operating rollers so that movement is accomplished with minimum effort. Component parts are light, durable and extremely simple. By varying the width and number of units, an assembly can be arranged for any size furnace. Consult Misco on your high temperature needs. Our wide experience in practical design is at your service, and you can depend on maximum endurance from Misco Products.

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HEAT RESISTING ALLOYS

CAST • ROLLED • FABRICATED

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FURNACE PARTS • ROLLER RAILS • ROLLER HEARTHS CONVEYOR ROLLS • TRAYS • RETORTS • CHAIN • MUFFLES WALKING BEAM CONVEYORS • CARBURIZING AND ANNEALING BOXES • DIPPING BASKETS • CYANIDE AND LEAD POTS • THERMOCOUPLE PROTECTION TUBES • PICKLING EQUIPMENT • CENTRIFUGAL CASTINGS • PRECISION CASTINGS • MISCELLANEOUS CASTINGS AND ROLLED BARS • SHEETS, PLATES, TUBES AND WELDING ROD FOR USE AT HIGH TEMPERATURE OR UNDER CORROSIVE CONDITIONS.

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Michigan Steel Casting Company

MISCO
Heat and Corrosion Resistant Alloys

One of the World's Pioneer Producers and Distributors of Heat and Corrosion Resisting Alloys

1998 GUOIN STREET • DETROIT 7, MICHIGAN

Personals

J. H. Ahrens, formerly technical engineer in the distribution department of the Hartford Electric Light Co., Hartford, Conn., has been promoted to the position of industrial power consultant.

Emmett H. Babcock has been employed by Cherry-Burrell Corp., Chicago, as metal finishing engineer.

Muzaffer Kebabcioglu, formerly employed by Cummins and Barnard Engineers, Inc., and a graduate of the University of Michigan, is now working for the Turkish government in its factories.

Formerly editor of *Metal Finishing*, **Richard A. Mozer** is now president of the Aluminum Plating Corp. of New York, Brooklyn, which company he started.

E. F. Lawrence is now on leave of absence from the Anaconda Copper Mining Co., Butte, Mont., to attend the University of Alabama.

W. J. C. Lewis has recently completed the course in metallurgical engineering at the University of Toronto, and is now employed at the Canadian Furnace Ltd., Port Colborne, Ont., as a trainee in blast furnace production.

L. H. Travis was separated from active duty in the U. S. Navy to take a position as chief metallurgist of the John Deere Des Moines works, Des Moines, Iowa.

Willard M. Harris has been transferred from the Lafayette, Ind., plant of the Aluminum Co. of America to the extrusions division of Alcoa at Cressona, Pa., where he will be chief plant metallurgist.

C. W. Lytton, formerly district manager of the Franklin, Pa., office of the Lincoln Electric Co., is now manager of the Buffalo office.

John H. Adams, Jr., is now sales engineer with Stanley G. Flagg & Co., Inc., Philadelphia.

Jean Sebille, formerly in charge of the Arcos Research Laboratory, Polytechnic Institute in Mons, Belgium, is now chief of the research department of S. A. Sambre Escaut at Hemiksem, near Antwerp.

Upon graduation from Purdue University, **Robert H. McCreery** has accepted the position of metallurgist with International Harvester Co. at its Evansville, Ind., works.

W. P. Achbach has joined Chrysler Corp., Highland Park, Mich., as metallurgical engineer upon his recent graduation.

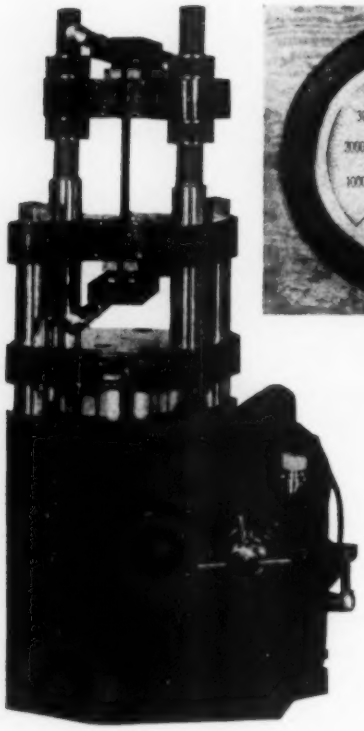
Robert H. Aaron is now vice-president in charge of engineering at Rhodes Lewis Co., Los Angeles, design and development engineers for the aircraft industry and other commercial sources.

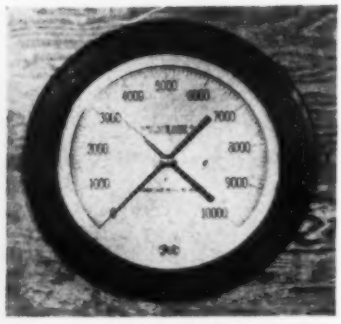
George Reed has been transferred by Timken Roller Bearing Co. from the metallurgical department of the Steel and Tube Div., Canton, Ohio, to the position of sales engineer for the same division in Houston, Tex.

Brooke Todd, for the past five years general manager of Beaumont Well Works Co., has organized the Beaumont Forging Co., Beaumont, Tex., of which he is president and general manager.

Richard D. Buckheit, formerly metallurgical observer in the open-hearth department of Crucible Steel Co. of America's Midland works, has joined Battelle Memorial Institute, Columbus, Ohio, to conduct research in metallography.

Tensile Testing Machine





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FOR TESTING SPOT-WELDS, STRIP, WIRE, ETC.

This machine is made in 10,000 and 20,000 lb. capacities and the operation is extremely simple. Movement of the ram is controlled by a graduated dial and spoked knob on the front of the machine. Various speeds are obtained by turning the dial to the right. A small movement to the left returns the ram to the down position.

In standard arrangement shown the grips are open sided permitting easy insertion of specimen. Pulling the handles together lightly engages the test piece after which the grips are self-acting. The pulling members are adjustable to take specimens 5 to 9" OA. or to your requirements.

The load is applied hydraulically by means of a gear pump of the rotary type. Pump gears are hardened and ground and shafts are ball-bearing mounted. The motor is mounted at the rear and is coupled directly to the pump.

Additional load gauges and various types of grips are available to suit requirements. This machine is readily adaptable to almost all special purposes within its capacity at slight extra cost.

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DETROIT . . . MICHIGAN

PRESSURE FIGHT! PRESSURE TIGHT!

A year at the bottom of the ocean does things to a tin can.

A can of coffee salvaged from a ship sunk at the height of coastwise submarine warfare was battered and wrinkled by the extreme undersea pressures. But it was not punctured on any surface nor at the soldered seams! The solder held!

Joining the seams of tin cans is only one of the many jobs done by Federated solder. From its complete line Federated can supply you with the *right* solder for *every* job, in all commercial sizes and compositions—bar, pig, body; drop, foil, ingot; acid core, rosin core, solid wire; triangle, strip, wiping, segment.

To order solder or any non-ferrous metal, call or write any of Federated's eleven plants or twenty-five sales offices across the nation.

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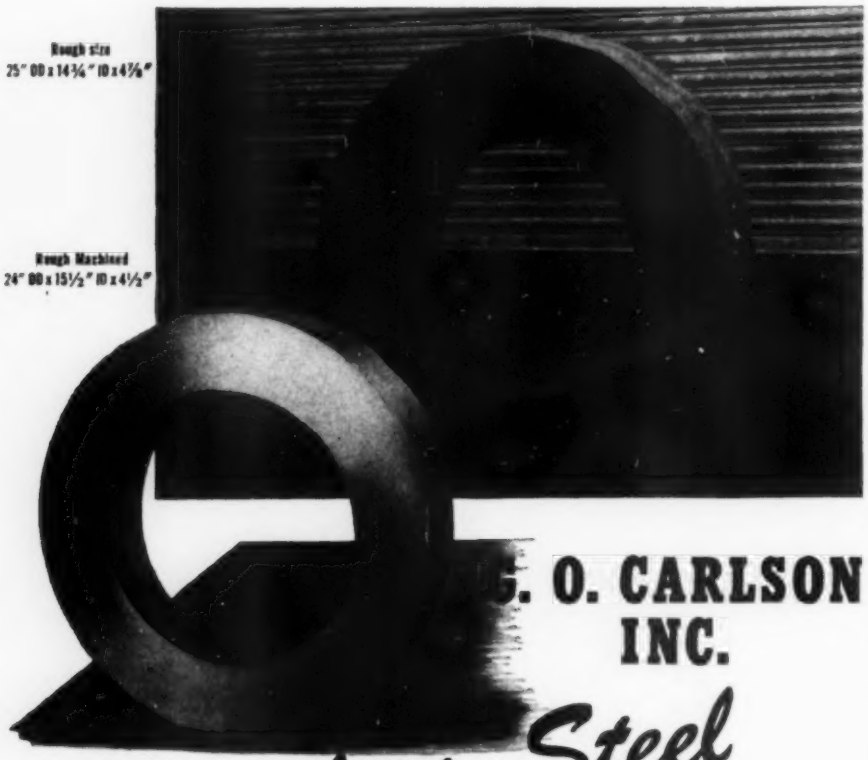
Division of American Smelting and Refining Company, 120 Broadway, New York 5, N. Y.



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Stainless Steel Forged Rings

G. O. Carlson, Inc. produces stainless steel forged rings in most analyses and in any reasonable sizes. These rings are sold in the "As Forged" condition, "Rough Machined" with allowances for you to finish, or "Finish Machined" to your exact size.

At all times, we have on hand a wide range of sizes and analyses of stainless steel forging stock, which enables us to give you prompt delivery of high quality forged rings. The production of this forging stock and these forged rings, in analyses to meet the highest specification requirements of the chemical industry, falls within the classification of routine production at G. O. Carlson, Inc. Further, we are always prepared to furnish other forged items such as discs, tube sheets, flanges, sleeves, etc. Therefore, if you want a dependable source of supply for stainless steel forgings, get in touch with G. O. Carlson, Inc.

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PLATES • FORGINGS • BILLETS • BARS • SHEETS (No. 1 Finish)

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Personals

Robert Zilligen is now employed as an assistant chemical engineer by Standard Oil Co. of Indiana, at Whiting, Ind.

Amiel Gelb, previously chief testing engineer of the aluminum division, Reynolds Metals Co., Louisville, Ky., has accepted the position of director of laboratories, South-Wind Div., Stewart-Warner Corp., Indianapolis.

M. L. Harlow has been appointed chief designer and specifications engineer of the Hodell Chain Co. (division of National Screw & Mfg. Co.), Cleveland.

Clo E. Armantrout has been transferred by the Bureau of Mines from Salt Lake City to College Park, Md., with the transfer of his department, the titanium section.

Robert E. Hopper, formerly with Air Research at Phoenix, Ariz., is now employed by Arabian American Oil as assistant metallurgical engineer at the refinery at Ras Tannurah, Saudi Arabia.

J. J. Zimmerman, formerly consulting engineer for sheet metal fabrication, Easy Washing Machine Corp., and chief tool engineer of the parts division of Reynolds Metals Co., has joined Playboy Motor Car Corp., Buffalo, N. Y., as chief production engineer.

N. C. Fick, of Battelle Memorial Institute, Columbus, Ohio, has been appointed metallurgist and deputy executive director of the Committee on Basic Physical Sciences, Research and Development Board, Washington, D. C.

John H. Timmers is now associated with the Armco research laboratories at Middletown, Ohio.

Chen Pao Sun is now professor of metallurgical engineering, National Pei-Yang University, Tientsin, China.

I. C. Mattson has been transferred from welding engineer in the fabrication division of Dow Chemical Co., Bay City, Mich., to metallurgist, development section, magnesium laboratories, at Midland, Mich.

W. Lee Williams, who served during the war at the U. S. Navy Engineering Experiment Station, has remained there in a civilian capacity to serve as assistant superintendent of the metallurgical laboratory.

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General Chemical **METAL FLUOBORATE** Solutions

Stemming from advanced wartime reseach by General Chemical, Metal Fluoborate Solutions have rapidly won an important place as electroplating chemicals, especially for their standout performance in lead, tin, lead-tin alloy, copper and zinc plating operations.

General Chemical's Metal Fluoborates offer electroplaters an unusual *combination of advantages* not available in other plating agents. Note the special features outlined here. Consider how important each one can be in terms of efficiency and economy in your operations!

1. No mixing or dissolving necessary . . . supplied in concentrated solution form.
2. Easier bath preparation.
3. Stability of bath composition.
4. Ease of control.
5. Practically 100% anode and cathode efficiency.
6. High conductivity.
7. Good covering power.
8. Fine-grained deposits of good color.
9. Faster, high-speed operation.

You should know more about these modern developments for better, easier electroplating. For detailed operating data, experimental samples or commercial quantities, write or phone nearest office below. When planning special operations, draw on the knowledge and experience of our technical specialists in setting up baths for test or full scale runs.

TECHNICAL BULLETINS AVAILABLE

Technical Information Manual ZF-1 . . . The New Approach to Zinc Plating.
Technical Information Manual LTF-1 . . . Lead-Tin Alloy Plating from the Fluoborate Bath.
Technical Information Manual CF-1 . . . Copper Fluoborate.

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FOR AMERICAN INDUSTRY

"FALLS BRAND" ALLOYS
AMERICA'S LARGEST PRODUCERS OF ALLOYS

"Falls"
50-50
NICKEL COPPER

Production costs are materially reduced through the use of "FALLS" 50-50 NICKEL COPPER.

Savings include . . .

— increased output
— less fuel consumption
— fewer rejected castings
— longer life for crucibles and furnace linings.

Write For Complete Details

NIAGARA FALLS
Smelting & Refining Division
Continental United Industries Co., Inc
BUFFALO 17, NEW YORK

Personals

The Carpenter Steel Co., Reading, Pa., announces that **Frank R. Palmer**, formerly vice-president in charge of sales, has been elected president of the company.

G. G. Marvin, previously associate professor of chemistry at Massachusetts Institute of Technology, has joined the U. S. Atomic Energy Commission as chief of the materials branch, production division.

W. D. Latiano, who was formerly metallurgist in the steel division of Western Automatic Machine Screw Co., is now president and sales manager of Ohio Metallurgical Service, Inc., Lorain, Ohio. Previous to being with Western Automatic, he was at National Tube Co., Ellwood City, Pa., for 20 years as metallurgist.

Upon receiving his M.S. degree from University of California, **Alfred P. Binsacco** was appointed process analyst in the process and materials engineering department of Northrop Aircraft, Inc., Hawthorne, Calif.

J. K. Mullen was transferred by General Electric X-Ray Corp. from managership of its Spokane, Wash., sales office to a similar position in Detroit.

J. Gill Stanley, who has been with Edgar T. Ward's Sons Co. for the past 14 years, has been appointed manager of the company's Buffalo warehouse and district sales manager for Columbia Steel & Shafting Co., Summerill Tubing Div.

William A. Gibson is now assistant professor of mechanics and strength of materials at Rensselaer Polytechnic Institute.

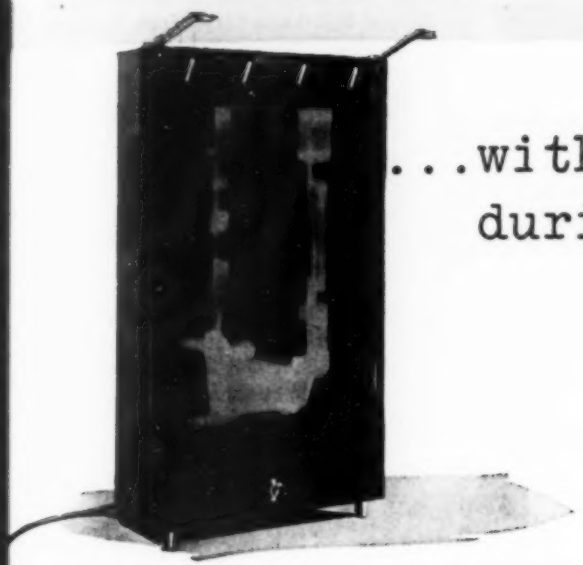
C. R. Mayne, formerly with the National Tube Co., Gary, Ind., is now in the development and research division of the International Nickel Co., New York City.

Dan L. Wertz has established a manufacturers' agency in Detroit for Upton Furnace Division of Commerce Pattern Co., John Ek Industries, and Crown Chemical Co.

The National Association of Corrosion Engineers has elected **F. L. LaQue**, who is in charge of the corrosion engineering section of the development and research division of the International Nickel Co., to the presidency of the group.

Increase sound casting yield...

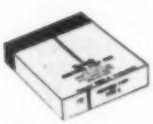
Progress in increasing sound foundry yield is due largely to foundrymen's adoption of new and proved practices and technics—both before and during production runs. Radiography is contributing greatly to improving foundry methods by providing records of the internal condition of the casting for detailed study.



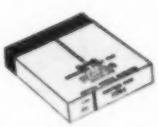
...with radiography before and during production runs...

Radiographic examination of pilot castings helps develop sound technics quicker . . . gets full production runs going sooner. Used as a spot check, radiography assures uniformly sound casting output. Result: radiography reduces rejections . . . increases sound yield . . . more than pays its own way.

For maximum radiographic visibility- use Kodak Industrial X-ray Films...

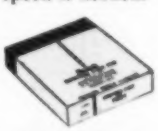


Kodak Industrial X-ray Film, TYPE A . . . for x-ray and gamma-ray work in sections where fine grain and high contrast are desirable for maximum sensitivity at moderate exposure times.



Kodak Industrial X-ray Film, TYPE K . . . designed for gamma-ray and x-ray radiography of heavy steel parts, and of lighter parts at limited voltages where high film speed is needed.

Kodak Industrial X-ray Film, TYPE M . . . first choice in critical inspection of light alloys, thin steel at moderate voltages, and heavy alloy parts with million-volt equipment.



Kodak Industrial X-ray Film, TYPE F . . . with calcium tungstate screens—primarily for radiography of heavy steel parts. For the fastest possible radiographic procedure.

They provide the high radiographic sensitivity —the combination of speed, contrast, and fine grain—required for the detail visibility you need in critical examination of castings.

For complete information on the types best adapted to your job, see your local x-ray dealer—or write to

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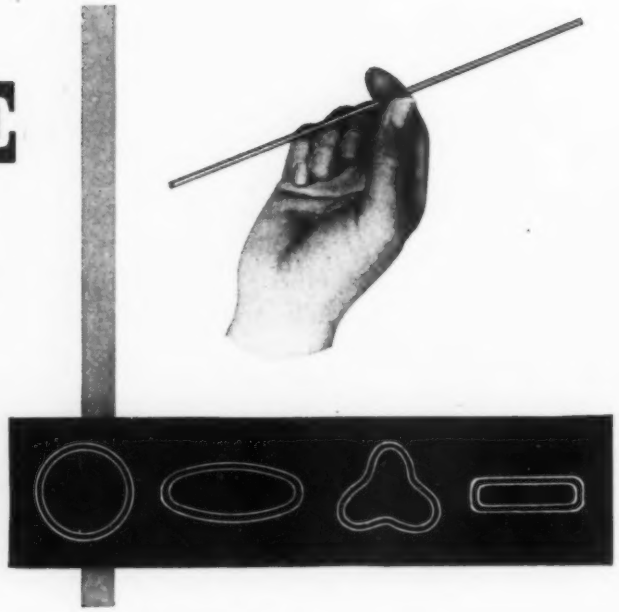

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SUPERIOR FINE SMALL METAL TUBING

(.010" to 5/8" O.D. Max.)

is an achievement of sound production techniques

You have your choice—specify OD-Wall, ID-Wall, or OD-ID—and the tubing cold drawn to your order at Superior will be held to surprisingly close tolerances. Tolerances, in fact, which until a few years ago, were possible only by costly grinding and screw machine operations. Now, with closely controlled cold drawing and annealing techniques, any two of the three basic dimensions are held rigidly in Superior production.

It is important to know that the dimensional accuracy of Superior tubing is more than "skin deep", that you can plan on a snug fit—and get it! Cleanly telescoping tubing—if that is what you require —*is a standard* product of the Superior Tube Company.

Bulletin #31, with concise information on Superior commercial tolerances, is available—we invite you to write for your copy.

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SUPERIOR TUBE COMPANY

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For Superior Tubing on the West Coast, call PACIFIC TUBE CO., 5710 Smithway St., Los Angeles 22, Cal. • ANgeles 2-2151

Personals

Formerly with the Kearny works of the Western Electric Co., **Clinton R. Dodd** has accepted the position of metallurgical engineer with the Kingston-Conley Electric Co., division of the Hoover Co., Cambridge, Ohio.

A. H. Roberson, for the past five years physical metallurgist in the alloy section of the U. S. Bureau of Mines, Salt Lake City, Utah, has been transferred to the Bureau station in Albany, Ore., where he will be engaged in research on zirconium and its alloys.

Formerly with Deloro Smelting and Refining Co., Ltd., **H. D. Forbes** is now employed as a metallurgical engineer with the Aluminum Co. of Canada, Ltd., at its Kingston works.

Robert W. Graham has recently been appointed assistant general superintendent of the Homestead District Works, Carnegie-Illinois Steel Corp.

A recent graduate of the University of Michigan, **Herbert S. Robinson** has been employed as a research metallurgist for American Smelting & Refining Co. in its central research laboratory at Perth Amboy, N. J.

W. H. Sparrow, formerly metallurgical engineer of the Sperry Gyroscope Co., is now chief of process control, Chance-Vought Aircraft Corp., Stratford, Conn.

Formerly research engineer at the University of California, **Charles H. Avery** has accepted the position of engineering superintendent of the Carol-of-California Co., Pasadena, Calif.

Leeds & Northrup Co. has transferred **H. R. Abey** from district manager of the Los Angeles office, where he has been for 19 years, to the same position in Philadelphia.

John P. Englert has been transferred from the Bureau of Ships, Washington, D. C., where he was in charge of the standby program for industrial plants, to the Charleston Naval Shipyard as senior industrial engineer, management planning and review division.

E. N. Blye has resigned from A. O. Smith Electrical Mfg. Co. to take a position as associate structural engineer with the Los Angeles Harbor Commission's engineering department.

accuracy guaranteed...

when you use CHROMEL-ALUMEL®
"extension" leads with your
CHROMEL-ALUMEL thermocouples

Your pyrometers are probably accurate . . . most of them are today. And, too, most of them are calibrated for dependably accurate CHROMEL-ALUMEL thermocouples. But they can still register *inaccurate* temperature-E.M.F. values if you're using so-called "compensating" lead wires. Here's why . . .

When "compensating" leads are used, wires of different composition are joined together forming thermo-electric junctions just outside the furnace. When these junctions get hot . . . as they very often do . . . or when one gets hotter than the other, the opposing E.M.F.s they generate become more and more unequal . . . and serious plus or minus errors are registered by your meter.

So if you're concerned with accurate temperature measurement, make sure your pyrometers are calibrated for *and equipped with* durable CHROMEL-ALUMEL couples. They carry a positive accuracy guarantee of ±5° between 32° and 660° F., and ± ¾% at temperatures above 660° F. And, of course, protect this fine accuracy by using only CHROMEL-ALUMEL *extension* leads. They belong together . . . and together they eliminate all possibility of "cold-end" errors! Our Catalog—58R contains complete technical information . . . want a copy?

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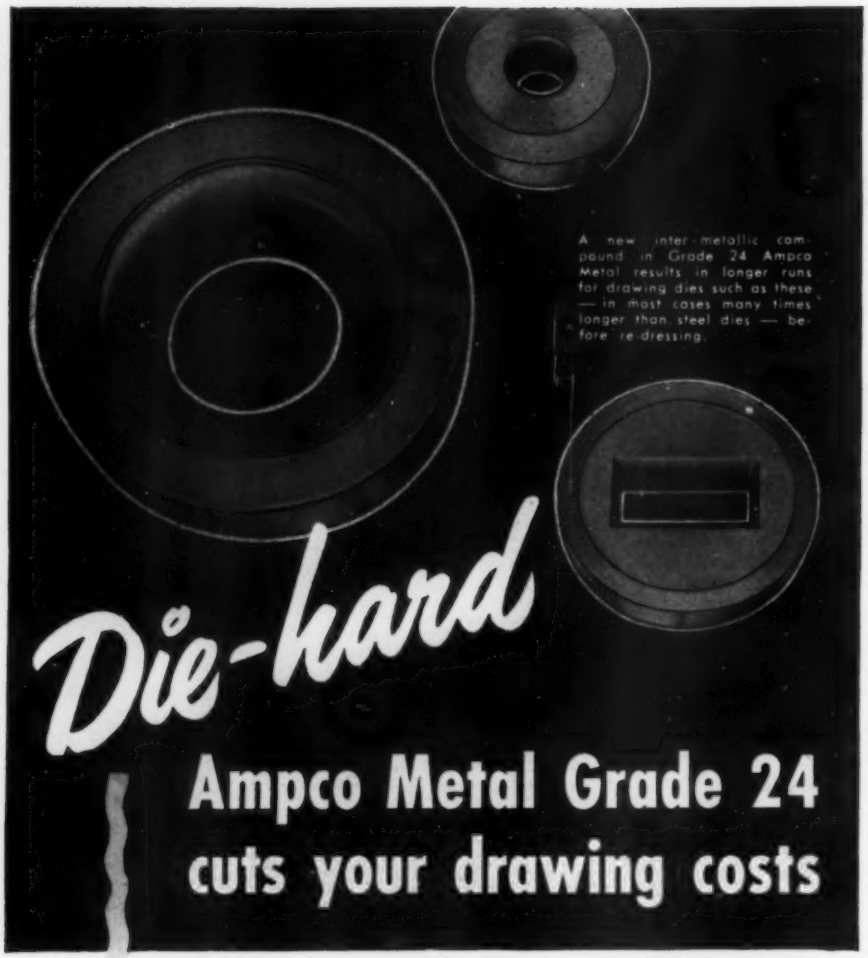
Heating Element Alloys ★ Heat Resistant Alloys ★ Thermocouple Alloys ★ Spark Plug Electrode Wire ★ Special Alloys of Nickel ★ Electric Heat Treating and Laboratory Furnaces


A new inter-metallic compound in Grade 24 Ampco Metal results in longer runs for drawing dies such as these — in most cases many times longer than steel dies — before re-dressing.
Die-hard
Ampco Metal Grade 24
cuts your drawing costs

Gives longer runs before re-dressing — no galling and loading on stainless steel

Here's the new Ampco Metal Alloy — Grade 24. It gives you more hardness and compressive strength than any other bronze — even more than Grade 22 Ampco Metal which you have used for your drawing and forming work in the past. Machinability of Grade 24 is about the same as that of Grade 22.

Dozens of disinterested shops have already tested this new alloy in die work. They *proved* that Grade 24 gives you 2 to 5 times the die life previously considered standard.

These tests also proved that Grade 24 Ampco Metal dies are superior to steel dies on many jobs, especially stainless steel. A typical test case showed a 77,000 run on an Ampco Metal die, compared to a 3000 run on a steel die. The Ampco Metal die does not seize or gall. There is less frequent need for re-dressing. As a result, you get longer runs at lower cost. Actual superiority varies according to die-tolerances and working stock.

Plan now to get more work per dollar from your dies. Use the longer-run advantages of Grade 24 Ampco Metal to avoid investment in more expensive carbide dies. See your nearby Ampco engineer today, for the complete cost-cutting story on Grade 24! Write for bulletins giving complete data today.

Ampco Metal, Inc.
Dept. MP-6, Milwaukee 4, Wisconsin
Field Offices in Principal Cities

Personals

Wieslaw Jedrzejowski is now design and development engineer with H. C. Evans & Co., Chicago.

Joseph J. Warga, formerly works metallurgist with Sperry Gyroscope Co., is now with the Kimble division of Owens-Illinois Glass Co. as development engineer.

Don C. Root, metallurgist, has transferred to the College Park (Md.) Station of the U. S. Bureau of Mines where research and investigation of titanium and its alloys are being conducted.

Columbia Steel Co. announces the appointment of **Joseph A. Burgard**, past chairman of the Los Angeles Chapter of the American Society for Metals, to the position of technical sales representative for the Columbia Steel Co. Mr. Burgard has been affiliated with Columbia for 19 years.

Hamilton Art Metal Corp., New Hyde Park, N. Y., announces the appointment of **George A. Meyer** as vice-president of the firm's die-casting division.

Robert F. Mehl, head of the department of metallurgical engineering at Carnegie Institute of Technology, delivered the Hatfield Memorial Lecture in London, England, May 5. The lecture was under the sponsorship of Sheffield University, Iron & Steel Institute, and the Royal Society. Dr. Mehl is also speaking before the Swedish Metallographers' Society and the Royal Institute of Technology in Stockholm, Sweden.

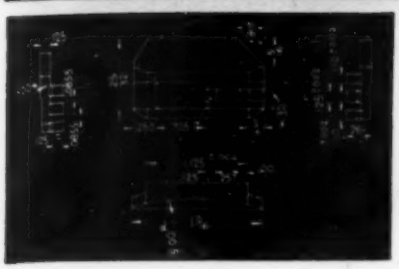
Formerly Buffalo district manager for the Copperweld Steel Co., **Frank B. Davis** is now operating as manufacturers' agent representing the Fitzsimons Steel Co., Copperweld Steel Co., and Josiyn Mfg. & Supply Co. in western New York and northeastern Pennsylvania.

Richard O. Stratton has been promoted from plant superintendent to production superintendent of the Trent Tube Mfg. Co., East Troy, Wis. Before his affiliation with Trent Tube, he was production metallurgist at Trent Engineering Co. and associated with Trent Tube in a consulting capacity.

Robert J. Gray, who was previously metallographer at the American Brake Shoe Co., now holds the same position at Oak Ridge National Laboratories, Oak Ridge, Tenn.

MISCO *Precision* STEEL and ALLOY CASTINGS

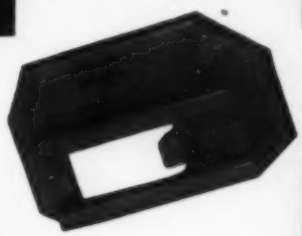
CAST TO MICROMETER TOLERANCES

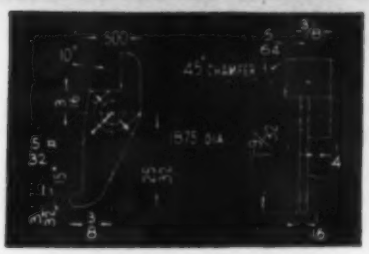


Replacing a part formerly produced from solid stock the precision casting eliminates costly machining operations.

Part:
SEWING MACHINE FEED DOG

Alloy: Miscrome 1 Weight: .6 oz. (A.I.S.I. Type 420 Nominal)





This intricate casting is used in the production of automotive generators and starters. The adoption of precision castings resulted in a cost saving of 94% on this part.

Part:
ROTOR WINDING PICK-UP FINGER

Alloy: Miscrome 5 Weight: .24 oz. (A.I.S.I. Type 440 Modified)

No measurable wear has been found on this part after thousands of miles of operation.

Part:
AUTOMOTIVE GOVERNOR FLY WEIGHT

Alloy: Miscrome 5 Weight: 1 oz. (A.I.S.I. Type 440 Modified)

Both parts of this actuator assembly are precision-cast to close tolerances. The use of this process eliminated forging die expenses, and resulted in great reduction of machining cost.

Part:
BRACKET SUPPORT AND CAP (AIRCRAFT)

Alloy: Miscrome 1 Weight: 5.2 oz. (A.I.S.I. Type 420 Nominal)

MISCO PRECISION CASTINGS OFFER THE FOLLOWING ADVANTAGES

1 Low-cost production of small intricate parts which would necessitate expensive machining operations if made by conventional methods.

2 Large quantity production of small parts in materials which are difficult or impossible to forge or machine.

3 Eliminating waste of expensive materials such as stainless steels or semi-precious metals during ordinary machining operations.

4 Production of parts which cannot be made as a single unit by any other manufacturing process.

5 Reproduction of intricate shapes in extremely fine detail without machining.

6 Dimensional accuracy can be maintained to plus or minus .004″ per inch of length, width, diameter or thickness. (This is an average figure which can be bettered for certain parts and materials.)

7 Very smooth surface finish. Profilometer readings average 70-80 micro inches on production castings.

8 Cast grain structures are in many instances advantageous over either forged or rolled structures.

9 Precision castings are relatively free from internal stresses, due to the slow cooling rate of the metal in pre-heated molds.

10 Soundness is assured through X-ray control of feeding technique and accurate control of pouring temperature and pressure.

11 Small or negligible tooling costs.

12 Quick deliveries due to minimum time required for tooling.

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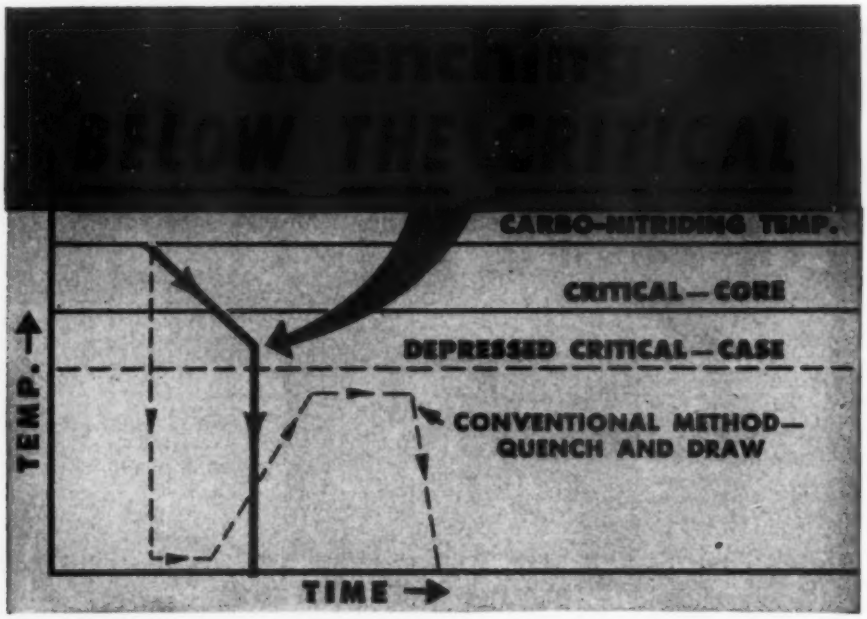

A *NEW* CASE-HARDENING TECHNIQUE WHICH

- Eliminates the Draw Furnace
- Gives File-Hard Case and Soft, Tough Core
- Cuts Distortion to a New Low
- Saves Time, Money and Floor Space

THIS NEW Holcroft process provides a carbo-nitrided case of superior wear resistance and a soft, tough core of maximum impact resistance—*without a draw.*

The work (plain carbon or alloy steel) is heated in a controlled atmosphere composed of generator gas, hydrocarbon gas and ammonia. Besides increasing the hardness, addition of nitrogen (from the ammonia) depresses the critical temperature of the case below the critical (Ar_1) of the core.

When the desired depth of case is obtained, the work is moved into an atmosphere cooling zone, where it is brought to a temperature *below* the critical of the core and *above* the critical of the case. The work is then quenched from this temperature, as illustrated.

Since the core is quenched below its critical, it undergoes no hardening, and distortion is negligible. The case, however, is made file-hard—more wear-resistant than a straight carburized case. Thus a superior quality of work is obtained, at worth-while savings in time, money and floor space.

This is one more example of Holcroft trail-blazing in heat-treat work of all kinds. This leadership in applied metallurgy is one reason why Holcroft furnaces—individually designed for specific applications—provide unsurpassed quality at lower cost in every high-production application. We invite your inquiries.

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Welding Armor Plate*

WELDING of armor plate was not considered by the British army officials before 1939, it being indeed the consensus of experts that such high-alloy steels were unweldable because the heated metal adjacent to the weld would harden into brittle martensite, and the original ballistic qualities in that region could not be restored without prolonged retreatments. Nevertheless it was known that French and German ordnance engineers were welding armor with some success as early as 1935.

First experiments in England were with the 3½% Ni-Cr-Mo armor up to 1¼ in. thick, heat treated to 225,000-psi. ultimate tensile strength. Welding was done with covered electrodes of ferritic alloy. Such welds would develop extensive "cold cracks" during the first two days after welding, usually in the heat affected zone or at the junction of weld and base metal, but not in the weld metal itself.

Shortly thereafter 18-8 Cr-Ni electrodes were used with much better success; cold cracks were avoided, although the 18-8 weld metal showed a tendency to crack while the joint was being run ("hot cracking"). It was later found that 2 to 3% molybdenum or 5% manganese reduced this tendency, and the Cr-Ni-Mo analysis became standard in the allied munitions works. Larger electrodes and high heat inputs are a supplementary help in avoiding hot cracks.

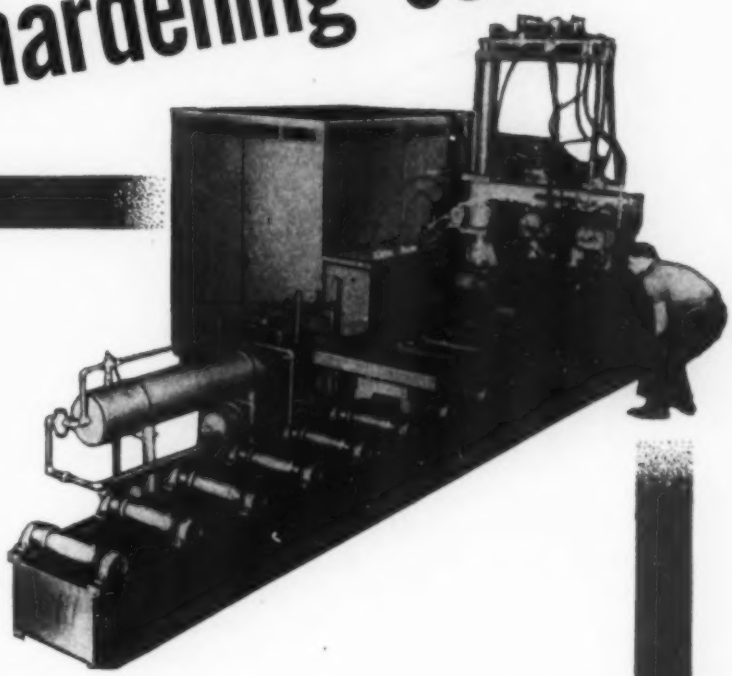
Metallurgically, the influence of molybdenum and manganese in eliminating the hot-short range of plain 18-8 is probably due to the tendency of these elements to retain islands of delta ferrite within the austenite, and supersaturated carbides coming out of solution in the cooling austenite tend to enter the delta ferrite rather than to accumulate at the austenitic grain boundaries.

Complete success in welding 1-in. homogeneous armor resulted when especial care was taken to avoid hydrogen-containing substances in the electrode coatings (such as moisture or cellulose). Hydrogen is considered to be *(Cont. on p. 866)*

*Abstract of "Developments in the Welding of Armor", by T. L. H. Butterfield. *The Welder*, April-June 1947, p. 26-32.

ELECTRONIC HEATERS ON THE JOB: LATHE-BED HARDENING

uniform hardness tougher lathe ways reduced hardening cost



A LONGER LEASE ON LIFE is now being given to machine-tool lathes at the Hendey Machine Company, Torrington, Conn. Thanks to the uniform hardness made possible by a G-E electronic induction heater, precision surfaces of lathe-bed ways remain "mirror-smooth" far beyond previous life expectancy . . . are less vulnerable to precision-destroying wear and accidental damage.

At this company, lathe beds are mounted on a movable carriage, and their way surfaces are progressed under the specially mounted inductor coil of a G-E 50-kw electronic heater for uniform, controlled heating and automatic quenching.

Using the G-E electronic heater, these lathe-bed wearing surfaces are heat-treated with results unmatched by former methods. Surface hardening is accomplished with close depth control, at a faster rate, and with assured uniformity.

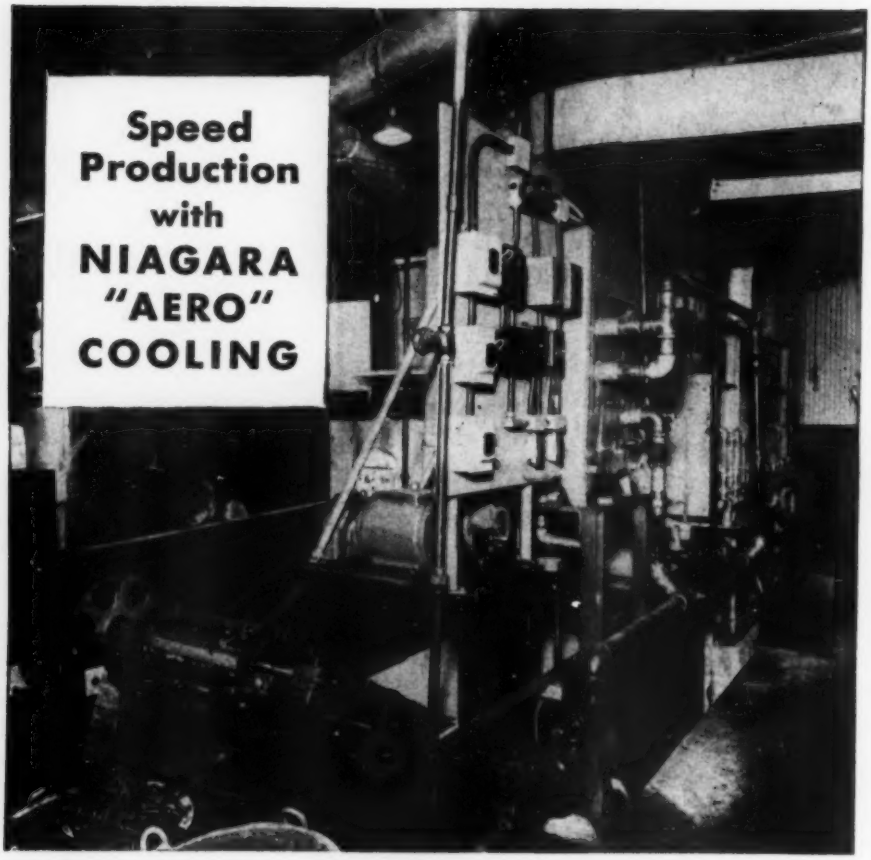
Net result: a better product through induction heating.

Electronic INDUCTION HEATERS

YOUR PRODUCT AND INDUCTION HEATING

Whether your product involves brazing, soldering, hardening, or annealing, be sure to get in touch with the Heating Specialist in the nearest G-E Office. His suggestions are very likely to result in higher production, lower cost, and better products, as they have for many other manufacturers. In the meantime, send for free bulletin GES-3290, "The How and What of Electronic Induction Heating." ***Sect. 675-178, Apparatus Department, General Electric Company, Schenectady 5, N.Y.***

GENERAL ELECTRIC



● This compact quench bath cooler increases production by furnishing ample cooling capacity for the highest speed of a continuous heat treating process. More important, it increases the net production result by preventing loss from rejected pieces. It maintains the specified temperature uniformly, removing heat at the rate of input. Also, it can automatically add heat at the start of a run to prevent loss during a warm-up period.

The NIAGARA AERO HEAT EXCHANGER is made in a wide range of sizes to handle any cooling load. It replaces both shell and tube cooler and cooling tower and its water saving repays its cost in a short time.

Other applications include jacket water temperature control for process equipment or engines, cutting oils, lubricants, hydraulic oils, transformers, electronic sets, controlled atmospheres, compressed air or gas cooling.

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Welding Armor

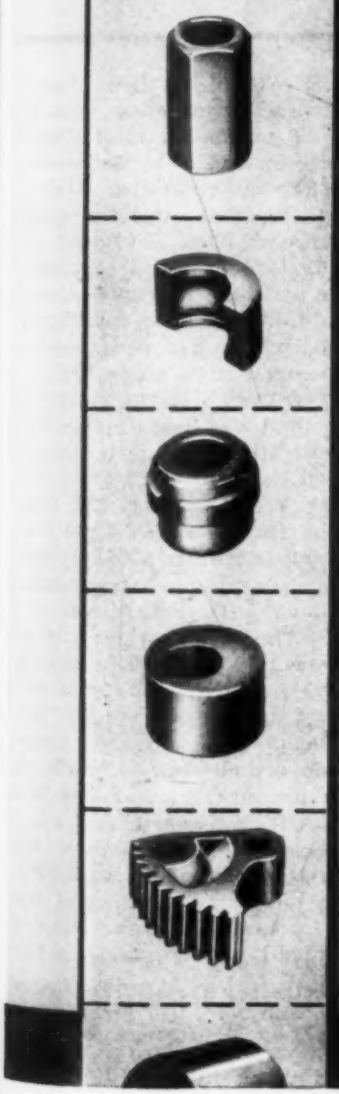
(From p. 864) a contributory factor to other causes of cracks, such as multi-axial shrinkage stresses at the joint, formation of hard, brittle layers of martensite, volume changes due to the gamma → alpha transformation — all of which set up stresses of high order. The addition of hydrogen is the straw that breaks the camel's back, although the elimination or mitigation of any of these factors greatly reduces the tendency to failure.

Much theorizing has been done to explain the practical findings that hydrogen-free austenitic electrodes are successful filler materials whereas welds with ferritic electrodes crack at lower levels of stress. No conclusion has been reached; it is now a pressing problem (to conserve strategic chromium and nickel) to develop satisfactory ferritic electrodes and coatings. Such a core wire should have sufficient alloy so the metal in the joint will have reasonably good ballistic properties; it should also have good "running" characteristics in large diameters.

As to hydrogen, the assumption is that molecules are dissociated in the arc atmosphere and atomic hydrogen absorbed by the weld metal as it is being deposited. Since the solubility of hydrogen in ferrite is considerably lower than in austenite, much gas will be evolved during the critical transformation that occurs when ferrite electrodes are used. It is thought that this gas, diffusing toward the regions of low concentration (base metal), builds up high pressures in submicroscopic cavities existing in the metal, and multi-axial stresses so induced are the cause of cold cracks. Austenitic weld metal, on this basis, is of advantage because it has much higher solubility, in the cold, than ferrite; there is also the possibility that such hydrogen in solution tends to stabilize the austenite at atmospheric temperatures.

Once the production of crack-free welds in heat treated armor up to 1-in. thick was solved, further developments were largely in welding techniques, principally in jigging so all welding could be done downhand, and toward larger and larger core wires with their increased rates of heat input and lowered cooling rates in the hardenable metal alongside. Electrodes of ⅝-in. diameter are about the limit *(Cont. on p. 868)*

We take our POWDER METALLURGY with a grain of salt



Perhaps you've heard claims that powder metallurgy is a "cure all" for every parts problem.

You haven't heard them from Moraine Products.

We've taken the realistic approach that metal powder parts must be competitive in *price*, *properties* and *performance* before they can do a manufacturer any lasting good. And our broad manufacturing experience tells us that there are still plenty of parts where powder metallurgy doesn't fill the bill.

On the other hand, we can point to a growing list of satisfied customers who use metal powder parts by Moraine in large volume. They depend on Moraine Products for finely finished parts, built to close commercial tolerances, possessing adequate physical properties for the application. And their savings in cost are considerable.

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Note on Property Specifications

We stated that metal powder parts must be competitive in properties. Now we'll point out that specifications often call for higher properties than the application requires. Metal powder parts with lower physicals than parts formerly used are giving better performance results for many of our customers.

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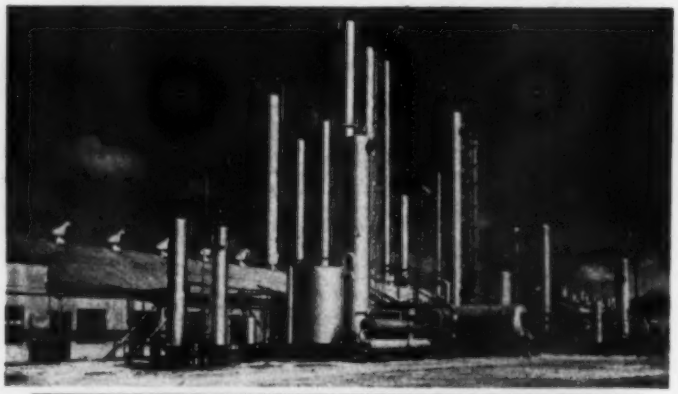

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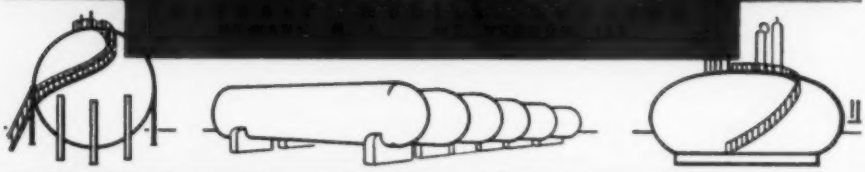

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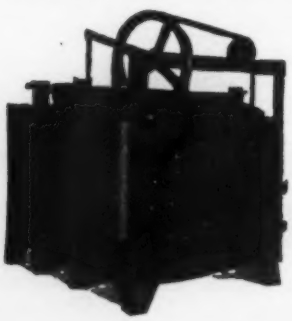

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Welding Armor

(Starts on p. 864) for manual operation; larger electrodes have been used on automatic equipment.

Other wartime developments included studies which limited the carbon content of weldable homogeneous armor to 0.35%. Heavy armor was successfully welded by coating the joint surfaces with 25-20 Cr-Ni austenitic electrodes before infilling with the 18-8-2½ Cr-Ni-Mo electrode. Base metal edges were also mildly preheated to 300° F., and warm work carefully screened from drafts. Multiple-run techniques depositing flat layers with maximum sized electrodes also contributed to the success.

Swedish Sponge Iron*

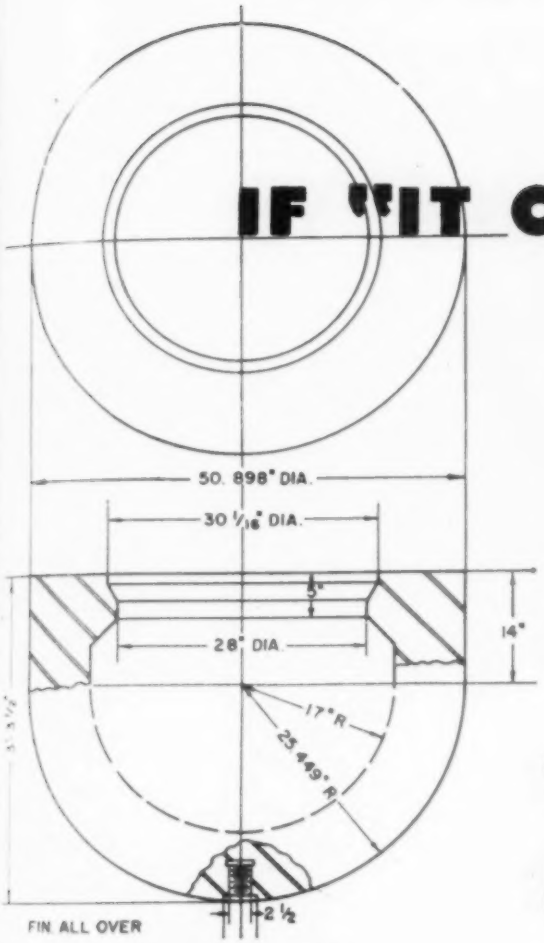
MUCH WORK has been done in several countries with the object of producing steel directly from ore instead of by the indirect blast furnace process. Only in Sweden, however, has the sponge iron process been developed successfully to a practical conclusion.

The first sponge iron process to be used in Sweden was the Höganäs method, which has been used on an industrial scale since 1911.

[ABSTRACTER'S NOTE: Interest in this method has been increased by the publication of more recent data by S. Eketorp, *Jernkontorets Annaler*, V. 129, 1945, p. 703; translated by the Iron and Steel Institute, Translation No. 275, July 1946. In the Höganäs process ceramic pots about 5 ft. high, made of a local fireclay, are charged with flat briquettes of a concentrate containing 71.5% Fe interspersed with layers of carbon prepared by mixing Höganäs coal with coke breeze. The pots are charged in batches in a long pit furnace, which is fired with gas from Swedish coal and is large enough for 35,000 pots. The charge is heated to about 2200° F. After a total time of about 12 days in the furnace, the pots are emptied by manual labor. *(Cont. on p. 870)*

*Abstracted from "The Use of Sponge Iron for Steel Production in Sweden", by M. Tigerschiöld and S. Eketorp. Translation in *Metallurgia*, V. 37, No. 220, 1948, p. 167-180.

IF "IT CAN'T BE DONE"



TRY MEEHANITE DIES

THE MEEHANITE DIE shown is regularly performing a single pressing operation about which it had been said "it can't be done." Its function is to cold press 5/16" steel plate into half-ball shapes. These forms are welded together to produce gas storage vessels.

Used in conjunction with Meehanite drawing and clamp rings, the punch is 51" in diameter, 39½" long, and has a metal thickness of 8½". Its weight is about 13,000 lbs. In less than a year's operation the die has been used to produce about 1000 vessels or 2000 pressings.

Meehanite dies for drawing, forming and stamping represent one of the outstanding contributions from a production standpoint, offered by the controlled, dependable, better properties of Meehanite castings. Their engineering characteristics include better tensile properties, a high compressive strength, *real* resistance to wear, and heat-treatability —all a result of metallurgical controls which provide a tough pearlitic matrix evenly dispersed with graphite flakes.

In other fields including those of heat and abrasion resistance as well as in those general engineering jobs where better quality is required, Meehanite castings have frequently been the answer when it was thought that—"it can't be done."

For further details about Meehanite dies write for our bulletin entitled "Meehanite—an 'All-Around' Die Material."

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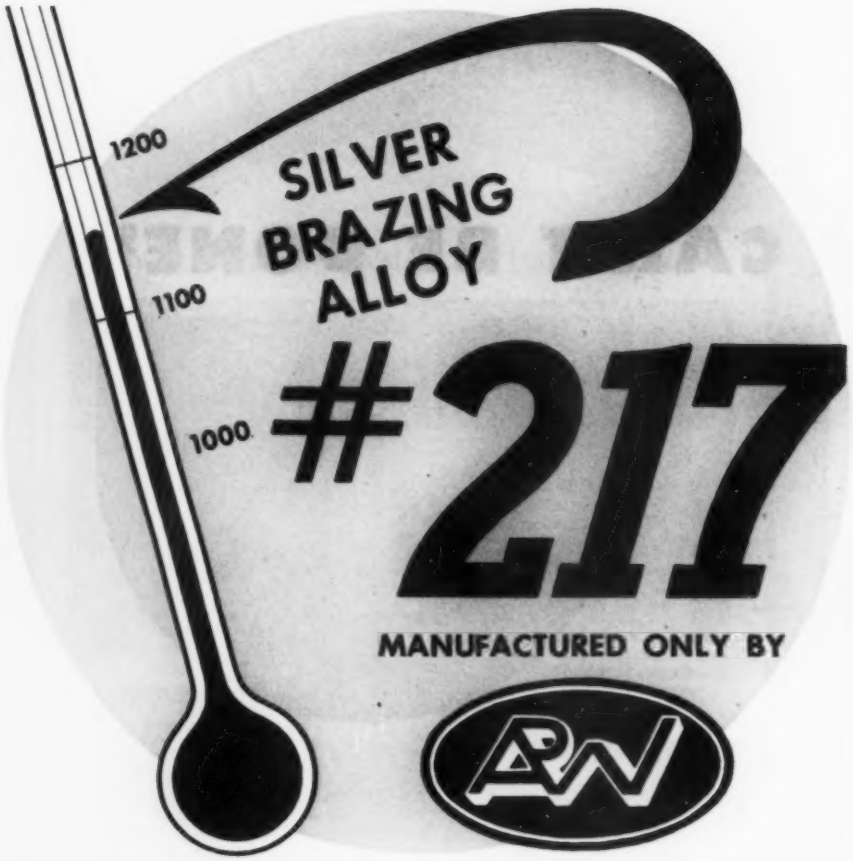

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Sponge Iron

(Cont. from p. 868) In the United States rather extensive experiments have been made recently with this type of process. See Bureau of Mines, Reports of Investigation 3819, 3822 and 3841, all published in 1945.

[The Wiberg process, based on the use of gas as a reducing agent, is more recent. This process has been described by E. Améen, *Jernkontorets Annaler*, V. 127, 1943, p. 227; *Iron Age*, V. 153, Jan. 20, 1944, p. 55-59, 150, and Jan. 27, p. 56-65. In the Wiberg process, sintered or lumpy ore is charged into the top of a shaft furnace. In the lower part of the shaft nearly pure CO is introduced at 1650 to 1830° F. While passing up through the shaft the gas reduces the ore to iron, and the CO_2 in the gas increases to 25 to 30%. About 75% of the gas thus formed is removed by means of a fan and is forced through an electric-arc gas producer where the CO_2 is reduced to CO, superheated and again introduced into the lower part of the shaft. The sponge iron produced is discharged at the bottom of the shaft.]

Both the Höganäs and Wiberg processes are in commercial use in Sweden today. In the Höganäs process it has been customary to use magnetite ore containing 71.5% Fe. The degree of reduction is high, usually about 96%. In the Wiberg process a sinter with 60% Fe has been used, but in a short time it is intended to change over to a concentrate with 65% Fe, with which a reduction of about 90% will be most convenient.

The advantages of the Höganäs method are: *(a)* There are no limits as to the minimum size of ore or concentrate, *(b)* no sintering is needed, *(c)* a reduction of about 96% can be obtained, *(d)* the cheapest possible fuel can be used for reduction and heating, and *(e)* the finished product (cakes) is free from any tendency to pulverize or dust. Disadvantages of this method are that the costs of labor and construction are high, and lump ores and some high-sulphur ores cannot be reduced.

The advantages of the Wiberg process are: *(a)* Sinter as well as lump ores can be reduced, *(b)* Swedish fuel can be used as a reduction agent, *(c)* the furnace is not costly, and *(Cont. on p. 872)*